United States
Environmental Protection
Agency

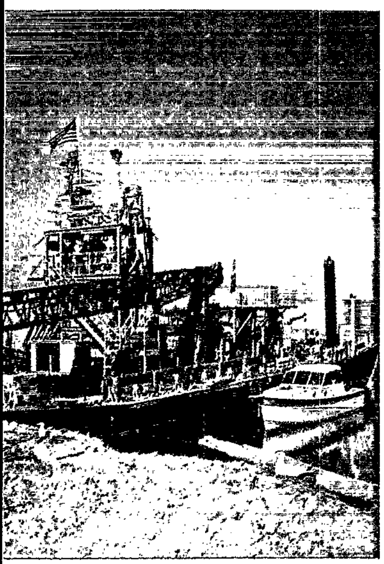
Office of Research and
Development
Washington DC 20460

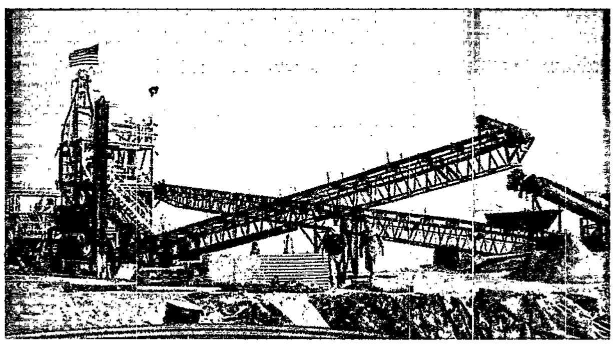
EPA/540/AR-92/075
September 1995

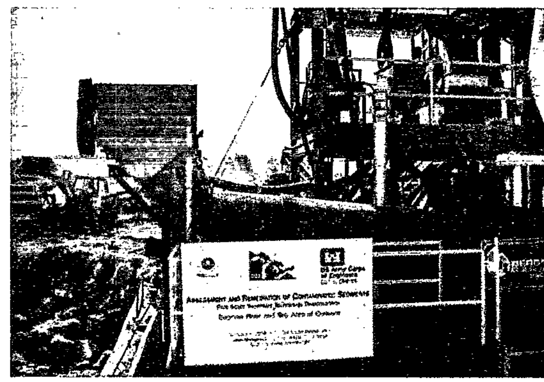
EPA

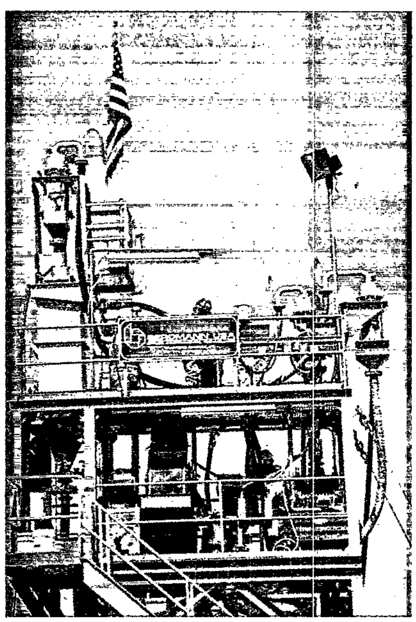
Bergmann USA Soil Sediment Washing Technology

Applications Analysis Report









SITE

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

CONTACT

S. Jackson Hubbard is the EPA contact for this report. He is presently with the newly organized National Risk Management Research Laboratory's new Land Remediation and Pollution Control Division in Cincinnati, OH (formerly the Risk Reduction Engineering Laboratory). The National Risk Management Research Laboratory is headquartered in Cincinnati, OH, and is now responsible for research conducted by the Land Remediation and Pollution Control Division in Cincinnati.

EPA/540/AR-92/075
September 1995

Bergmann USA
Soil Sediment Washing Technology

Applications Analysis Report

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency (USEPA) under Contract No. 68-C0-0048 and the Superfund Innovative Technology Evaluation Program. It has been subjected to the Agency's peer review and administrative review, and it has been approved for publication as a USEPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems ; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

This document provides an evaluation of the performance of the Bergmann USA Soil/Sediment Washing System and its applicability for the treatment of soils or sediments contaminated with organic and/or inorganic compounds. Both the technical and economic aspects of the technology were examined.

A demonstration of the Bergmann USA unit was conducted under the Superfund Innovative Technology Evaluation Program at the U.S. Army Corps of Engineers' Confined Disposal Facility in the Saginaw Bay of Like Huron. Operational data, along with sampling and analysis information, were carefully compiled to establish a data base against which other available data, as well as the vendor's claims for the technology, have been compared and evaluated. Conclusions concerning the applications at other sites with different contaminants and soil types were drawn.

The following conclusions were derived mainly from the results of the Demonstration Tests and supported by other available data: (1) the process effectively separates the <45-micron particles, the coarse fraction (>45-microns), and the humic fraction from the input feed; (2) PCB contamination in the input feed was concentrated and isolated in the output fines and output humic fraction; the larger coarse fraction was greatly reduced in PCB contamination; (3) the distribution of inorganic contaminants in the output streams echoed that of the PCBs; (4) the volume reduction of contaminated material in the output streams is a cost effective approach to site remediation prior to utilizing more expensive treatment technologies.

This demonstration was conducted for the Risk Reduction Engineering Laboratory (now the National Risk Management Research Laboratory) in May-June 1992, and work was completed as of August 1993.

Contents

Contents (Continued)

Tables

Tables (Continued)

Figures

Abbreviations and Symbols

AQMD	Air Quality Management District
ARAR	Applicable or Relevant and Appropriate Requirements
ARCS	Assessment and Remediation of Contaminated Sediments
BDAT	Best Demonstrated Available Treatment
BTEX	Benzene, Toluene, Ethyl benzene, and Xylene
CAA	Clean Air Act
CDF	Confined Disposal Facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cf	Cubic feet
CFR	Code of Federal Regulations
CWA	Clean Water Act
DMS	Dense Media Separator
$	U.S. Dollar
°F	degree Fahrenheit
FWQC	Federal Water Quality Criteria
g	gram
gal	Gallons
GLNPO	Great Lakes National Program Office
gpm	Gallons per Minute
hr	Hour
kg	Kilograms
kW	Kilowatts
lb	Pounds
mm	Millimeter
mg	Milligram
NAAQS	National Ambient Air Quality Standards
NPDES	National Pollutant discharge Elimination System
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
PCB	Polychlorinated Biphenyls
POTW	Publicly Owned Treatment Work
ppm	Parts per million
PSD	Prevention of Significant Deterioration
%	Percent
RCRA	Resource Conservation and Recovery Act
rpm	Revolutions Per Minute
RREL	Risk Reduction Engineering Laboratory
SAIC	Science Applications International Corporation
SARA	Superfund Amendment and Reauthorization Act
SDWA	Safe Drinking Water Act
SITE	Superfund Innovative Technology Evaluation
TSCA	Toxic Substances Control Act
TSD	Treatment Storage, and Disposal
USACE	United States Army Corps of Engineerrs
USEPA	United States Environmental Protection Agency

Acknowledgments

This report was prepared under the direction and coordination of Jackson S. Hubbard, USEPA Superfund Innovative Technology Evaluation (SITE) Program Manager in the National Risk Management Research Laboratory (formerly the Risk Reduction Engineering Laboratory) in Cincinnati, Ohio. Contributors and reviewers for the report were Gordon Evans, Teri Richardson, and Robert Stenberg of the EPA-NRMRL in Cincinnati, Ohio; and Jim Galloway and Frank Snitz of the U.S. Army Corps of Engineers in Detroit, Michigan.

This report was prepared for USEPA's SITE Program by the Process Technology Division of Science Applications International Corporation (SAIC) for the USEPA under Contract No. 68-CO-0048.

Section 1

Executive Summary

1.1 Introduction

This report summarizes the findings of an evaluation of the Soil/Sediment Washing System developed by Bergmann USA. The study was conducted under the Superfund Innovative Technology Evaluation (SITE) Program. A week-long Demonstration Test of the technology was performed by the U.S. Environmental Protection Agency (USEPA) as part of this Program. The results of these tests, along with supporting data from other testing performed by the U.S. Army Corps of Engineers (USACE) and other background information, constitute the basis for this report.

The Bergmann USA Soil/Sediment Washing System is a separation technology which relies on the grain size and density variations within a waste matrix to separate organic and metal contaminated waste into clean and concentrated output streams. Thus, reducing the volume of the initial waste that requires treatment prior to disposal. This separation is accomplished by adding water to the contaminated solids and directing the resultant slurries through a series of separating devices including:

- A trommel unit to separate out fractions coarser than 6 mm.
- A series of three cyclone separators.
- A dense media separator (DMS) to facilitate the removal of light organic particles.
- A three-stage attrition scrubbing cell to remove surficial contaminants from the sand grains.
- A partitioned dewatering screen to recover both the humic fraction and the washed coarse fraction from their respective slurries.
- A clarifier to separate out the fines with the aid of polymer flocculants.

Bergmann USA specializes in the process design, engineering, and drafting of equipment that is used for separating contaminated soils into individual size fractions. The equipment is fabricated by a sister company for whom Bergmann USA is a representative. As such, Bergmann USA is not a remediation contractor, but the representative of the supplier of the equipment for the remediation.

1.2 Conclusions

A number of conclusions may be drawn from the evaluation of this innovative technology. The most extensive data were obtained during the SITE Demonstration Tests; data from other testing activities have been evaluated in relation to SITE Program objectives. The conclusions drawn are:

- The process can successfully separate the <45-micron grain size fraction from the input soil/sediment, concentrate this fraction into the output fines, and produce two other output streams: (1) a humic fraction and (2) a washed coarse fraction.
- PCB contamination in the input stream is concentrated in the output fines and the humic fraction. It is anticipated that other organic compounds would follow this trend.
- On a mass basis, the largest output stream is the washed coarse fraction. The total mass of this fraction is a function of the grain size distribution in the input feed.
- The concentration of organic contaminants (PCBs) in the washed coarse fraction during the Demonstration Tests was a small fraction of the input feed concentration.

- Inorganic concentration in the washed coarse fraction is dependent on the particular element. The concentration of compounds in the washed coarse fraction is a function of the clay content of the input feed because the Bergmann USA System does not completely separate the input feed into the specified output streams and fines may be found in the washed sediment.

- Depending on initial concentrations in the feed, both the contaminated fines and the humic fraction may require treatment by extractive, destructive or immobilization processes prior to disposal.

- When water soluble substances are present in the input feed, the washwater may require treatment prior to disposal (carbon adsorption, ion exchange, reverse osmosis, etc.).

- If volatile compounds are found in the input feed, then some form of protection is required to ensure that ambient air regulatory levels are not exceeded.

- The rotary trommel unit did not perform according to expectations. The addition of a deagglomeration unit (not used due to space limitations) should aid in redirecting contaminated "fines" in stream S2 back into the washing process.

- The process is modular in design so that additional equipment can be added or removed to improve the efficiency of the soil/sediment separation. All modules used in the separation process are proven technologies commonly used in the mineral processing industry.

- This technology is suitable for land-based soils as well as river and harbor sediments. The feed should contain no more than 40% silt and clay (<45-micron) material; the solid humic content of the feed should not exceed 20% by volume.

- The on-line factor of the system is high. Full-scale Bergmann USA plants typically operate for extended periods of time with an on-line factor of 90 to 95%.

- Bergmann USA Soil/Sediment Washing Systems are available in sizes from 5 tons/hr to 300 tons/hr.

- The cost of utilizing the Bergmann USA System is a function of the required feed rate. The cost for a 5 tons/hr unit with an on-line factor of 90% is $151/ton. The cost for a 100 ton/hr system for the same on-line factor is $42/ton. These costs include excavation costs but do not include the final disposal costs for the output streams.

1.3 Results

The focus of the Applications Analysis is to assess the ability of the process to comply with Applicable or Relevant and Appropriate Requirements (ARARs) and to estimate the cost of using the technology at a Superfund site. To evaluate this technology, separation of media by grain size (<45 microns) and isolation of the associated contamination achieved by the technology are appraised as part of this report. Appendix C presents detailed Demonstration Test results and is supported by the data presented in the Case Studies in Appendix D.

- On a mass basis, an average of approximately 22.9% of the input feed used during the Demonstration Tests were particles <45 microns in diameter. Of these input particles, 0.419% were found in the output humic fraction (S5), 29.2% were found in the washed coarse fraction (S6), and 70.4% were found in the clarifier underflow or contaminated "fines" (S7) in Test 1. For Test 2 (system in operation with surfactant) the distribution was: 0.738% in the humic fraction, 32.9% in the washed coarse fraction, and 66.4% in the clarifier underflow.

- Neglecting the output contribution of the rotary trommel screen oversize, the washed coarse fraction (sand and gravel) output mass made up an average of approximately 91% of the total mass output for Test 1 and Test 2.

- The overall average concentration of PCBs in the inlet feed was approximately 1.35 mg/kg. During Test 1, the average concentrations of the PCBs in the output streams were as follows: humic fraction (S5), 10.4 mg/kg; washed coarse fraction (S6), 0.194 mg/kg; clarifier underflow or fines (S7), 4.61 mg/kg. During Test 2, the concentrations were: humic fraction, 13.4 mg/kg; washed coarse fraction, 0.189 mg/kg; and clarifier underflow, 3.68 mg/kg.

- Eleven metals were identified in the feed stream. The overall (Test 1 and Test 2) average concentration of these metals in the feed ranged from a low of 13.1 mg/kg for vanadium to a high of 27,000 mg/kg for calcium. The overall average distribution of vanadium in the output streams was: 23.3 mg/kg in the humic fraction (S5), 6.20 mg/kg in the washed coarse fraction (S6), and 50.8 mg/kg in the clarifier underflow (S7). The overall average distribution for calcium was: 21,700 mg/kg in the humic fraction, 14,400 mg/kg in the washed coarse fraction, and 77,900 mg/kg in the clarifier underflow. Other metals detected in the feed sediment, with the exception of aluminum and lead, tended to follow the general trend of these two elements.

- During the week-long (five days, eight hours/day) Demonstration, the Bergmann USA Soil/Sediment Washing System operated with an on-line factor of 100%.

Section 2

Introduction

2.1 *The SITE Program*

In 1986, the USEPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) established the Superfund Innovative Technology Evaluation (SITE) Program to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its eighth year, SITE is helping to provide the treatment technologies necessary to implement new federal and state cleanup standards aimed at permanent remedies, rather than quick fixes. The SITE Program is composed of four major elements: the Demonstration Program, the Emerging Technology Program, and the Measurement and Monitoring Technologies Program and the Technology Transfer Program.

The major focus of the SITE Program has been on the Demonstration Program, which is designed to provide engineering and cost data on selected technologies. To date, the demonstration projects have not involved funding for technology developers. USEPA and developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. The USEPA is responsible for sampling, analyzing, and evaluating all test results. The result is an assessment of the technology's performance, reliability, and cost. This information will be used in conjunction with other data to select the most appropriate technologies for the cleanup of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to the USEPA's annual solicitation. The USEPA will also accept proposals at any time when a developer has a treatment project scheduled with Superfund waste. To qualify for the program, a new technology must be at the pilot or full scale and offer some advantage over existing technologies. Mobile technologies are of particular interest to the USEPA.

Once the USEPA has accepted a proposal, the USEPA and the developer work with the USEPA Regional Offices and state agencies to identify a site containing wastes suitable for testing the capabilities of the technology. The USEPA prepares a detailed sampling and analysis plan designed to thoroughly evaluate the technology and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several months, depending on the length of time and quantity of treated waste required to assess the technology. After the completion of a technology demonstration, the USEPA prepares two reports, which are explained in more detail below. Ultimately, the Demonstration Program leads to an analysis of the technology's overall applicability to Superfund problems.

The second principal element of the SITE Program is the Emerging Technology Program, which fosters the further investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies could lead to the development of a system ready for field demonstration. The third component of the SITE Program, the Measurement and Monitoring Technologies Program, provides assistance in the development and demonstration of innovative technologies to better characterize Superfund sites.

2.2 *SITE Program Reports*

The analysis of technologies participating in the Demonstration Program is contained in two documents: the Technology Evaluation Report and the Applications Analysis Report. The Technology Evaluation Report contains a comprehensive description of the demonstration sponsored by the SITE Program and its results. It gives a detailed description of the technology,the site and waste used for the demonstration, the sampling and analyses performed during the test, the data generated, and the quality assurance program.

The scope of the Applications Analysis Report is broader and encompasses estimation of the Superfund applications and costs of a technology based on all available data. The Applications Analysis Report compiles and summarizes the results of the SITE demonstration, the vendor's design and test data, and other laboratory and field applications of the technology. It discusses the advantages, disadvantages, and limitations of the technology.

Based on available data on pilot- and full-scale applications, costs of the technology for different applications are estimated in the Applications Analysis Report. The Report discusses factors such as site and waste characteristics that have a major impact on costs and performance.

The amount of available data for the evaluation of an innovative technology varies widely. Data may be limited to laboratory tests on synthetic waste, or may include performance data on actual wastes treated at the pilot or full scale. In addition, there are limits to conclusions that can be drawn from a single field demonstration regarding Superfund applications. A successful field demonstration does not necessarily assure that a technology will be widely applicable or fully developed to the commercial scale. The Applications Analysis Report attempts to synthesize whatever information is available and draw reasonable conclusions. This document will be very useful to those considering the technology for Superfund cleanups and represents a critical step in the development and commercialization of the treatment technology.

2.3 Key Contacts

For more information on the demonstration of the Bergmann USA Soil/Sediment Washing Technology, please contact:

1. USEPA Technical Project Manager concerning the SITE Demonstration:

   Mr. Jack S. Hubbard
   USEPA
   Risk Reduction Engineering Laboratory
   26 West Martin Luther King Drive
   Cincinnati, Ohio 45268
   (513) 569-7507

2. Vendor concerning the process:

   Mr. Richard P. Traver
   Bergmann USA
   1550 Airport Road
   Gallatin, TN 37066-3739
   (615) 452-5525

Section 3

Technology Applications Analysis

3.1 Introduction

This section of the report addresses the applicability of the Bergmann USA Soil/Sediment Washing System towards pre-treatment of various potential types of soil and soil contaminants and is based primarily upon the results obtained from the SITE demonstration as well as additional tests performed by U.S. Army Corps of Engineers (USACE). Since the results of the Demonstration Tests provide the most extensive data base, conclusions about the technology's effectiveness and applicability to other potential cleanups are based mainly on those results. The Demonstration Test results are presented in detail in the Technology Evaluation Report. Additional information on the Bergmann USA technology, including vendor's claims, a brief process description, a summary of the Demonstration Test results, and reports on outside sources of data using the Bergmann USA technology are provided in Appendices A through D.

Following are the overall conclusions drawn on the Bergmann USA technology. The *"Technology Evaluation"* subsection discusses the available data from the Demonstration Test, the USACE tests, and literature provided by Bergmann USA. This subsection also provides more details on the conclusions and applicability of the Bergmann USA process.

3.2 Conclusions

The effectiveness of the Bergmann USA Soil/Sediment Washing System in separating the coarse fraction of material (sand and gravel) from the humic (leaves, twigs, roots, decaying vegetation, etc.) and fine (<45-micron, 325 mesh) fractions of material was tested during the SITE Demonstration. The SITE Demonstration Test was conducted at the USACE's Confined Disposal Facility (CDF) in the Saginaw Bay of Lake Huron, just offshore of Essexville, Michigan. The USACE also investigated the performance of the Soil/Sediment Washing System as a component of the Assessment and Remediation of Contaminated Sediments (ARCS) Program initiated by the Great Lakes National Program Office (GLNPO).

The objective of the SITE Demonstration was to investigate if the Bergmann USA Soil/Sediment Washing System is capable of:

- Separating the <45-micron particle size fraction from the bulk feed material;
- Concentrating organic contamination of the feed material into the output fines and humic fraction and leaving a washed coarse fraction; and
- Concentrating inorganic contamination of the feed in the same manner as the organic contamination.

In general, this innovative technology is successful in separating the waste feed into a series of physically unique streams (liquid, solid, and slurry). Each stream was consistent in its particle size, density, and moisture content. Nonetheless, each stream was significantly different than the other streams. PCB and metals contamination were effectively concentrated in the humic fraction and the fines.

The conclusions drawn from reviewing all available data on the Bergmann USA Soil/Sediment Washing System are:

- The process can successfully separate the <45-micron grain size fraction from the input soil/sediment, concentrate this fraction into the output fines, and produce two other output streams: (1) a humic fraction and (2) a washed coarse fraction.
- PCB contamination in the input stream is concentrated in the output fines and the humic fraction. It is anticipated that other organic contaminants would follow this trend.

- On a mass basis, the largest output stream is the washed coarse fraction. The total mass of this fraction is a function of the grain size distribution in the input feed.

- The concentration of organic contaminants (PCBs) in the washed coarse fraction during the Demonstration Tests was a small fraction of the input feed concentration.

- Inorganic concentration in the washed coarse fraction is dependent on the particular element. The concentration of compounds in the washed coarse fraction is a function of the clay content of the input feed because the Bergmann USA System does not completely separate the input feed into the specified output streams and fines may be found in the washed sediment.

- Depending on initial concentrations in the feed, both the contaminated fines and the humic fraction may require treatment by extractive, destructive or immobilization processes prior to disposal.

- When water soluble substances are present in the input feed, the washwater may require treatment prior to disposal (carbon adsorption, ion exchange, reverse osmosis, etc.).

- If volatile compounds are found in the input feed, then some form of protection is required to ensure that ambient air regulatory levels are not exceeded.

- The rotary trommel unit did not perform according to expectations. The addition of a deagglomeration unit (not used due to space limitations) should aid in redirecting contaminated "fines" in stream S2 back into the washing process.

- The process is modular in design so that additional equipment can be added or removed to improve the efficiency of the soil/sediment separation. All modules used in the separation process are proven technologies commonly used in the mineral processing industry.

- This technology is suitable for land-based soils as well as river and harbor sediments. The feed should contain no more than 40% silt and clay (<45-micron) material; the solid humic content of the feed should not exceed 20% by volume.

- The on-line factor of the system is high. Full-scale Bergmann USA plants typically operate for extended periods of time with an on-line factor of 90 to 95%.

- Bergmann USA Soil/Sediment Washing Systems are available in sizes from 5 tons/hr to 300 tons/hr.

- The cost of utilizing the Bergmann System is a function of the required feed rate. The cost for a 5 tons/hr unit with an on-line factor of 90% is $151/ton. The cost for a 100 ton/hr system for the same on-line factor is $42/ton. These costs include excavation costs but do not include the final disposal costs for the output streams.

3.3 Technology Evaluation

The following discussions utilize all available information to provide more detailed conclusions on the process. A summary of the data from the Demonstration Tests is presented in Appendix C; limited data from other tests conducted on this technology may be found in Appendix D, "Case Studies." Detailed estimates regarding the cost of using this technology are presented in Section 4, "Economic Analysis."

The system evaluated during the Demonstration Test was a barge-mounted pilot-scale unit. The barge was moored at the CDF and the input soil was fed from the CDF to the system by means of a series of conveyors. The feed rate for the Soil/Sediment Washing System during the Demonstration Test was approximately 4 tons/hr; the unit is sized for up to 5 tons/hr. The water used for the process was taken directly from the Saginaw Bay. For this sized unit, the process initially requires approximately 10,000 gallons of water, with a constant make-up of approximately 28 gpm during operation. The water required for the soil/sediment washing unit need not be potable; however, it must be free of debris. Therefore, the water fed to the system was passed through a 40-micron basket strainer to remove mussels, fish, and other debris. Other Bergmann USA units have undergone analysis, but this unit has been subjected to the most extensive testing. For the purposes of this Applications Analysis Report, only an evaluation of this Soil/Sediment Washing System has been performed.

The Bergmann USA Soil/Sediment Washing System is made up of individual components (trommel, cyclone separators, attrition scrubbers, etc.) that, when combined, are used to separate the input feed into the various output streams. All of the components used in the process are proven technologies used extensively in the mineral processing industry.

The washed coarse fraction (sand and gravel) output stream may be used for a variety of purposes. These include, but are not restricted to: beach supplement, road fill, or landfill cover. The washed coarse fraction is only capable of supporting limited vegetation; therefore, nutrients must be added if it is to be used for horticultural purposes.

The feed soil used for the SITE Demonstration Test consisted of sediments previously dredged from the Saginaw River. These sediments are considered to be granular in nature. The material is defined as a silty or clayey sand. Other constituents such as mussel shells, twigs, leaves, bark, etc. were also present. The soil was contaminated with low levels of polychlorinated biphenyls (PCBs) and heavy metals from industrial activities along the Saginaw River.

The Demonstration was conducted over a five-day period and was divided into two Tests. During Test 1, the unit operated for at optimum conditions four consecutive eight-hour days with a feed rate of approximately 4 tons/hr. Test 2 was similar to Test 1 except that it was conducted over a one-day period and a surfactant was added to the system. The surfactant used was Moncosolve 210 and was added at the approximate rate of 2 lb surfactant/ton feed soil. Bergmann USA's objective in adding surfactant was to demonstrate that this can be accomplished without disrupting system operations (e.g., without foam buildup). Bergmann USA recognized that due to low input concentrations and the absence of any "tar balls" in the feed, the surfactant would have little bearing on the distribution of PCBs in the output streams. In applications where the starting concentrations are much higher and where these concentrations are found in selected areas of the input feed, Bergmann USA anticipates the use of surfactant will increase the system's ability to distribute organic contaminants into the appropriate output streams by solubilizing and removing residual organics from the washed sediments.

The evaluation presented in this Applications Analysis Report focuses on the separation of the <45-micron particle size fraction from the bulk feed material. In addition, the distribution of PCBs and specific metals in all of the input and output streams are evaluated to determine if the contaminants were concentrated and isolated in the fines and the humic fraction. Mass balances are also discussed for total mass, total solids, total PCBs, and specific metals.

3.3.1 Particle Size Separation

The Bergmann USA Soil/Sediment Washing System used during the Demonstration Testing is designed to reduce the volume of contaminated sediments through the use of particle size separation. The separation is accomplished largely through the use of cyclone separators, mechanical devices used for many years in the mineral processing industry. It is generally assumed that the contaminant-rich fines are associated with particles with a diameter of <74-microns (200 mesh). In full-scale operation (>20 tons/hr), Bergmann USA utilizes 26-inch cyclone separators designed to make a particle size break at 74 microns. For this Demonstration, a finer cut was made at 45 microns due to constraints imposed on the cyclone separator's diameter by the selected feed rate. Since the Demonstration feed rate was planned for 5 tons/hr, Bergmann USA selected a 9-inch diameter cyclone separator to make a split at 45 microns. To a large degree, it is the efficiency of this separation which determines the amount of fines associated with the corresponding contamination level of the coarse fraction. For the Demonstration Tests, particle-size analysis was performed to determine the quantity of <45-micron material within the solids content of each output stream.

For these tests, simple gravity and size separations were used to clean the input feed. However, if the feed contamination was of a different form (i.e., lead shot), then other standard separation processes such as spiral concentrators, mineral jigs, or froth flotators could be employed instead.

The average proportion of <45-micron particles in the input feed was approximately 22.9% with an associated range of 9.90 to 35.2%. Particles in the <45-micron range were detected in the rotary trommel screen oversize (S2), the humic fraction (S5), the washed coarse fraction (S6), and the clarifier underflow or fines (S7). Figure 1 shows the locations of these sampling points and Appendix A gives a detailed process description.

The occurrence of a large portion of fines within the rotary trommel screen oversize was both unexpected and undesired. This stream is supposed to carry only leaves, twigs, shells and other >6-mm debris found in the raw dredged sediments. The addition of a log washer or similar deagglomeration unit operation to the oversize product discharge of the rotary trommel screen should aid in redirecting the fines from the oversize stream back into the sediment washing process. This was not possible during the Demonstration Tests due to space limitations on the barge. Data suggest that any additional fines introduced to the sediment washing process through improved trommel operation would be divided among the output product streams (S5, S6, and S7) in roughly the same proportions as described below. As such, fines detected in the rotary trommel screen overflow have been excluded from this discussion of particle size data and subsequently all contaminant calculations. If the fines rejected by the rotary trommel screen oversize (S2) are not neglected then the distribution of fines in all other effluent streams would be

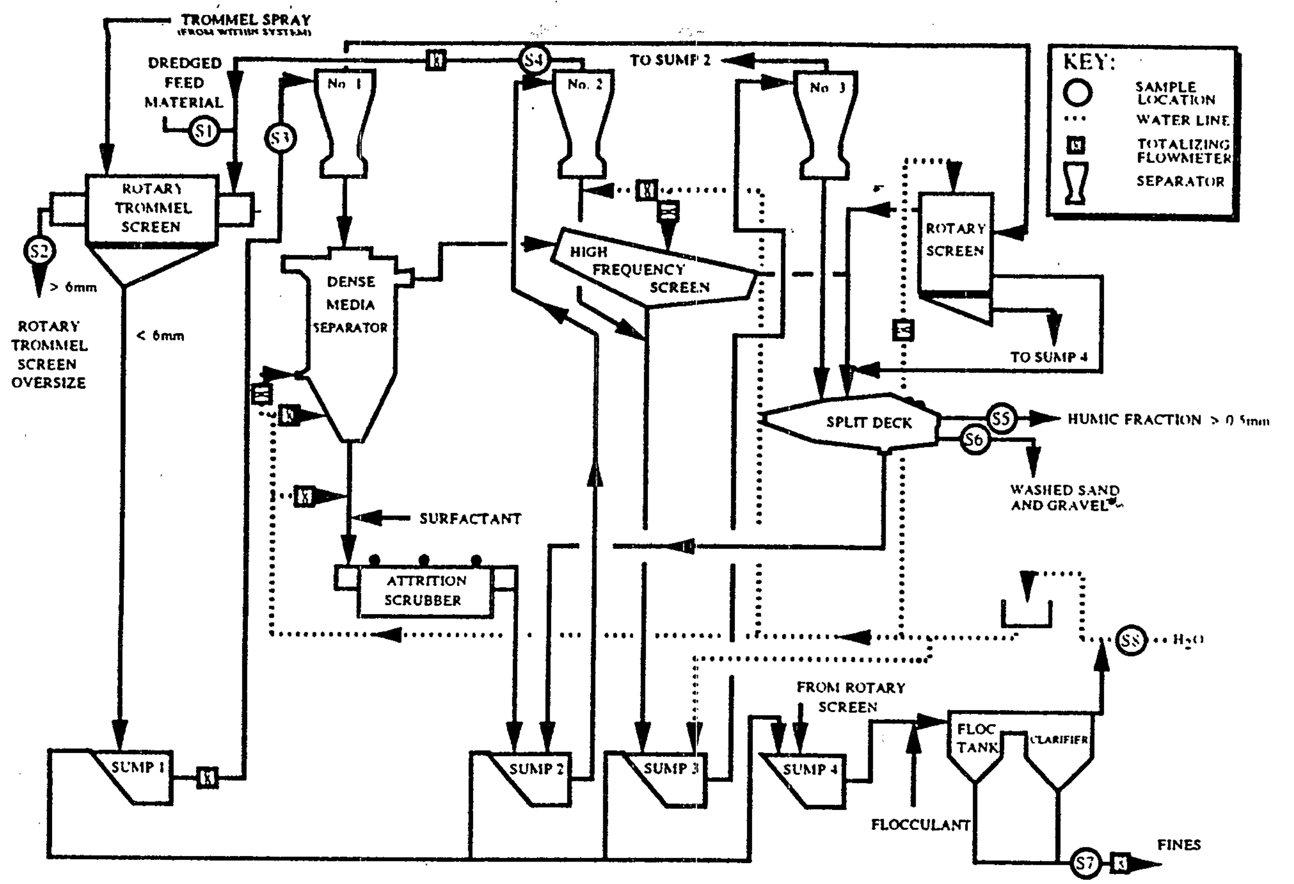


Figure 1. Sampling Locations for the Bergmann USA System

reduced by a total of approximately 20%. This in turn should impact the PCB and metals concentration by the same amount. The impact on efficiency by adding stream S2 is very small and almost negligible for most streams.

The objective of these tests was to concentrate the output fines in the clarifier underflow. For Test 1, the average distribution of output fines on a mass basis (as determined by mass of <45-micron particles in underflow to mass of <45-micron particles in all effluent streams) shows 70.4% in the clarifier underflow, S7 (see Figure 2). The associated range was 61.3 to 79.5%. The data show that the <45-micron particle size dominates the clarifier underflow stream and comprises an average of 94.4% of its solids. In contrast, the fine particles remaining in the washed coarse fraction are more dispersed and make up only 3.3% of its total solids content.

The average proportion of output fines on a mass basis during Test 2 shows 66.4% in the clarifier underflow (see Figure 2). The clarifier underflow solids contain 94.4% fine particles, whereas fine particles make up 5.0% of the washed coarse fraction. The results indicate that concentration of the output fines in the clarifier underflow is possible, and that the process does indeed concentrate a majority of the fines in this stream.

As shown in Figure 2, during Test 1, the average relative distribution of fines (<45-microns) among the other output product streams was as follows: 0.4% in the humic fraction (S5), and 29.2% in the washed coarse fraction (sand and gravel), the remainder being in the clarifier underflow. Data show that the dominant grain sizes in the washed coarse fraction stream are similar to those found in the humic fraction. It is the difference in density between heavy sand in the washed sediments and the light humic particulate matter which makes separation of these two streams possible.

The results for Test 2 are similar. On a mass basis, the humic fraction contained 0.8% of the <45-micron particles in the output streams and the washed coarse fraction (sand and gravel) contained 32.9% (see Figure 2).

There is reason to believe that the Bergmann USA Soil/Sediment Washing System Evaluated during the SITE Demonstration can consistently separate the majority of the <45-micron fines independent of the type of soil providing that the soil contains no more than 40% silt and clay and the humic content is less than 20%.

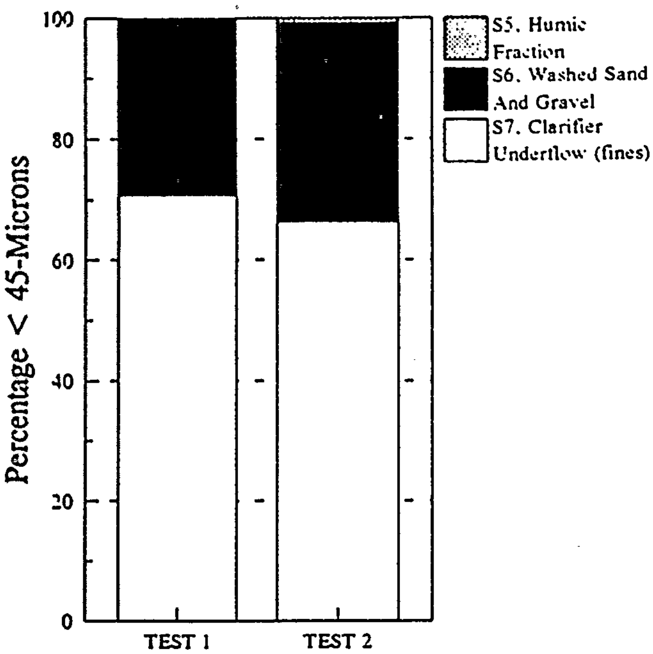


Figure 2. **<45-Micron Distribution Data for the Output Streams**

3.3.2 Distribution of PCBs

During the Demonstration Tests, PCBs were detected in the rotary trommel screen oversize (S2), the humic fraction (S5), the washed coarse fraction (S6), and the clarifier underflow (S7). As with the presence of fines in the rotary trommel screen oversize, the presence of PCBs within the rotary trommel screen oversize was also unexpected. It was anticipated that the >6-mm debris in the dredged sediment would only serve as a minor host to organic contaminants given its small surface area-to-volume ratio and its inorganic nature (shells, rocks, etc.). The PCBs appear, therefore, to be carried by the fines in the rotary trommel screen overflow. Redirecting the fines back into the main process stream as previously discussed should redirect most of the PCBs as well. Additional PCBs entering the system via the fines would probably divide among the output product streams in roughly the same proportions as seen in the Demonstration Tests. As such, PCBs detected in the rotary trommel screen overflow have been excluded from this discussion of PCB distributions.

The overall (Test 1 and Test 2) average concentration of PCBs in the feed stream was approximately 1.35 mg/kg with a 95% confidence interval of 1.20 to 1.51 mg/kg. The only PCB found during the testing was Aroclor 1242. A detailed explanation of the identification and quantification of this Aroclor is given in the companion document to this report, the Technical Evaluation Report.

Figures 3a and 3b illustrate the distribution of PCBs among the output product streams for Tests 1 and 2. Figure 3a shows the PCB concentration in each output stream (S5, S6, and S7), while Figure 3b shows the distribution of PCBs for each output stream in terms of mass (as a percent of the total PCB output, S5 + S6 + S7).

During Test 1, the average relative distribution of PCB mass among output product streams was as follows: 59.3% in the clarifier underflow; 30.0% in the washed coarse fraction; and 10.7% in the humic fraction. The data also show that the clarifier underflow stream had an average PCB concentration of 4.61 mg/kg on a dry weight basis. In contrast, the PCB concentration of the washed coarse fraction was only 0.194 mg/kg, approximately 24 times less than the concentration in the fines.

Results for Test 2 are similar and imply that the surfactant had no measurable effect on the distribution of PCB mass. During Test 2, the process separated the PCBs as follows: 57.2% in the clarifier underflow; 26.2% in the washed coarse fraction; and 16.6% in the humic fraction. The clarifier underflow solids contained 3.68 mg/kg PCBs, whereas the concentration of PCBs in the washed coarse fraction was 0.189 mg/kg, approximately 19 times less than the concentration in the fines.

The highest concentration of PCBs is in the humic fraction, with an average concentration of 10.4 mg/kg for Test 1 and an average concentration of 13.4 mg/kg for Test 2. This was expected and was due to the preferential partitioning of PCBs, an organic compound, to organic material within the solid humic stream.

The preferential partitioning of the PCBs into the fines and the humic fraction is indicative of the partitioning that can be expected for any similar organic compound in this soil/sediment washing system. If high levels of organic compounds (PCBs, PAHs, PCP, etc.) or "tar balls" are present in the feed, then the addition of surfactants into the unit can aid in the removal of contaminants from the coarse particles.

3.3.3 Distribution of Metals

Demonstration Testing of the Bergmann USA Soil/Sediment Washing System identified eleven metals (specified in Appendix C). Although the samples were analyzed for all

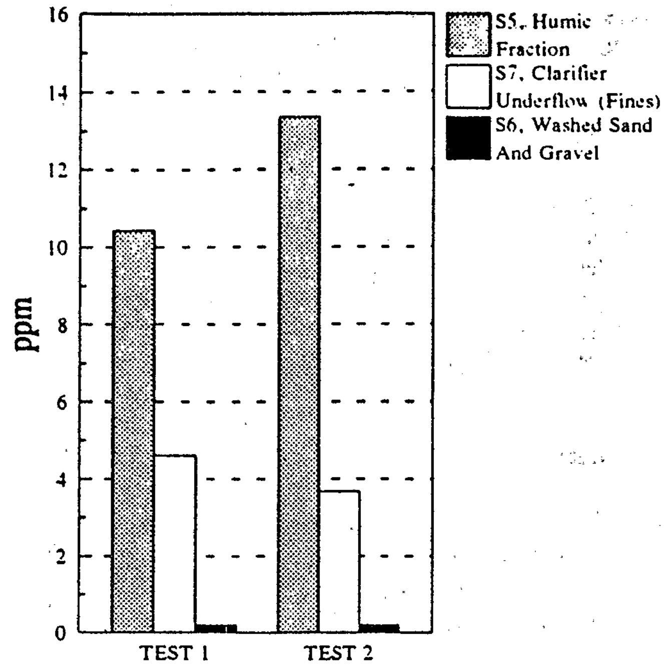


Figure 3a. PCB Concentration Distribution Data

the metals specified by SW-846 Method 6010 and mercury, only these eleven metals were present in high enough concentrations to allow a suitable evaluation of the technology. Three metals that are regulated under the Resource Conservation and Recovery Act (RCRA) were detected too infrequently to be used to evaluate the

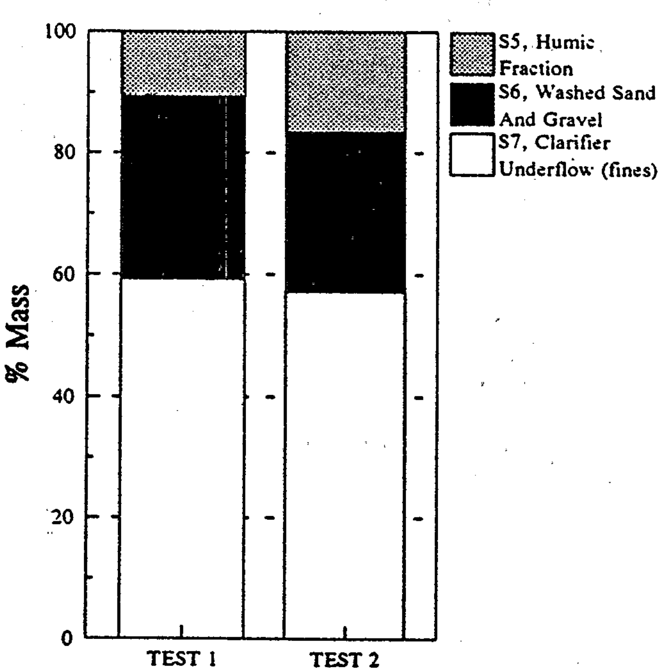


Figure 3b. PCB Mass Distribution Data

technology. These metals were cadmium, chromium, and mercury. One RCRA regulated metal (arsenic) was analyzed for, but not detected. For the purpose of the discussion presented in this report, only results for copper and lead will be included. All other identified metals (except aluminum) followed the general trend of copper and are discussed further in the Technical Evaluation Report. Aluminum is included in the summary presented in Appendix C.

The analytical methods employed during the Demonstration Tests to determine the metals content of each stream only report the metals as elements and not as any compound of that element. It is known, however, that the metals were present in the form of compounds that behaves differently than the elements themselves. This limitation of the analytical methods employed for metals determinations highlights the need for treatability studies due to the composition of contaminants in the soil being treated and other factors before full-scale remediation of a site can be initiated.

All identified metals were detected in the rotary trommel screen oversize (S2), the humic fraction (S5), the washed coarser fraction (S6), and the clarifier underflow (S7). As noted for PCBs, the occurrence of metals within the rotary trommel screen oversize was also unexpected, and like the PCBs, the metals also appear to be carried by the fines in the rotary trommel screen overflow.

The distribution of copper into the various output streams is presented schematically in Figure 4a in terms of concentration and in Figure 4b in terms of mass. The average input concentration of copper over the testing period was approximately 22.5 mg/kg. The figure shows that the washed coarse fraction has a concentration of approximately 7.81 mg/kg of copper during Test 1 and 9.49 mg/kg during Test 2. The overall average concentration of copper in the washed coarse fraction was approximately 8.15 mg/kg. This leads to a cleanup efficiency of approximately 63.6%.

Table 1 presents a summary of the cleanup efficiencies for the metals detected except aluminum and lead. Aluminum and lead are not included in this table because their behavior was not consistent with the other metals. Alumina is a component of clay and therefore, the behavior of aluminum with respect to the soil/sediment washing of a clay material (i.e., the feed) could not be evaluated. The unusual behavior of lead is discussed in Section 3.3.4, "Mass Balances."

The cleanup efficiency is based on the effectiveness of the system to separate the input feed into the required output streams and the grain size distribution of the feed soil/sediment. That is, if the feed soil has a low clay

Table 1. Summary of Clean-up Efficiencies and Mass Balance Closures for Metals

Metal	Clean-up Efficiency (%)	Mass Balance Closure (%)
Magnesium	44.7	87.8
Calcium	46.7	84.7
Vanadium	53.8	89.6
Copper	63.6	75.3
Potassium	67.4	86.5
Iron	69.0	75.1
Barium	81.6	68.0
Zinc	82.7	71.7

content, the concentration of contaminants in the washed sand and gravel should be low (assuming successful operation of the system). On the contrary, if the feed soil has a high clay content, then the concentration of contaminants remaining in the washed sand and gravel after processing will be proportionally higher. This is because clay has a high concentration of fines, and the process does not separate 100% of the fines into the clarifier underflow, but leaves a fraction of the fines in all the output streams.

Figure 4a shows that the concentration of copper is evenly distributed between the clarifier underflow and the humic fraction. Other metals typically show that the highest concentration of a particular metal is found in the clarifier underflow. The humic fraction, although possessing significant contamination, does not have the same affinity for metals as it does for organic compounds.

Figure 4b shows that a large amount of contaminant, in terms of mass, is found in the washed coarse fraction. However, since this stream is also the largest output stream in terms of mass, the corresponding concentration is very low as seen in Figure 4a. This behavior was typical of the metals investigated during the Demonstration Tests.

Lead was distributed in the various output streams in a similar manner to that of the other elements. Figures 5a and 5b show this distribution.

3.3.4 Mass Balances

For the Demonstration Tests, the ratio of the total mass of all output streams to the total mass of all input streams was

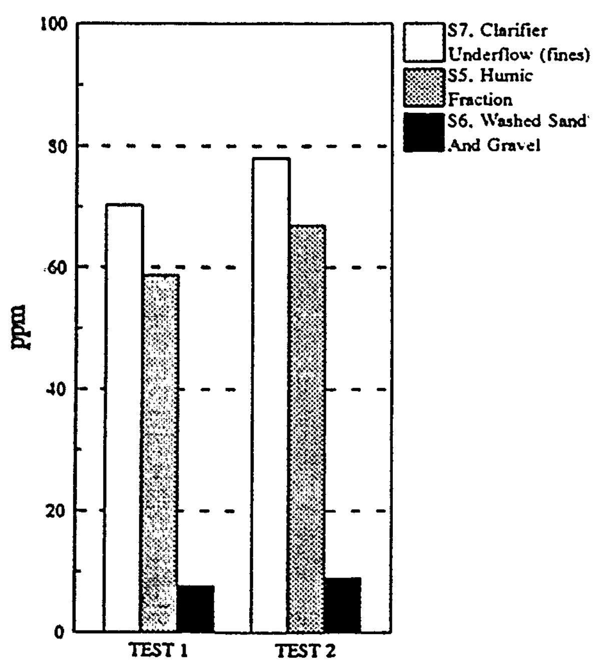


Figure 4a. Copper Concentration Distribution Data

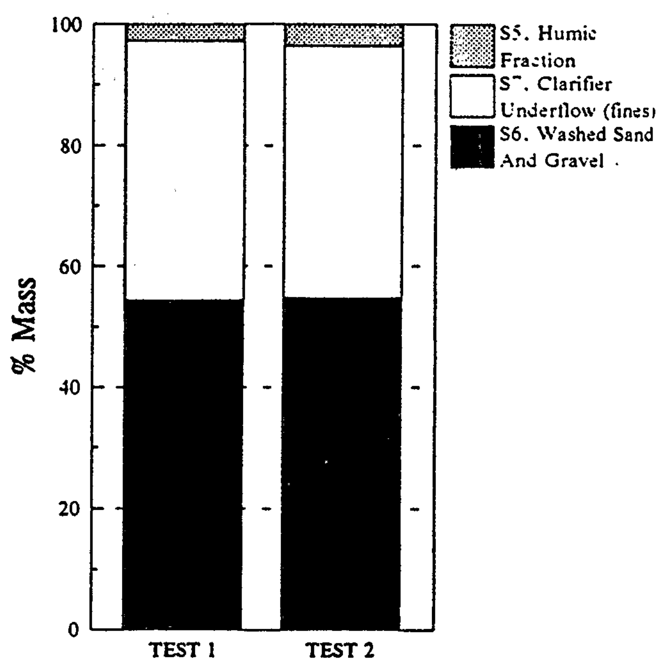


Figure 4b. Copper Mass Distribution Data

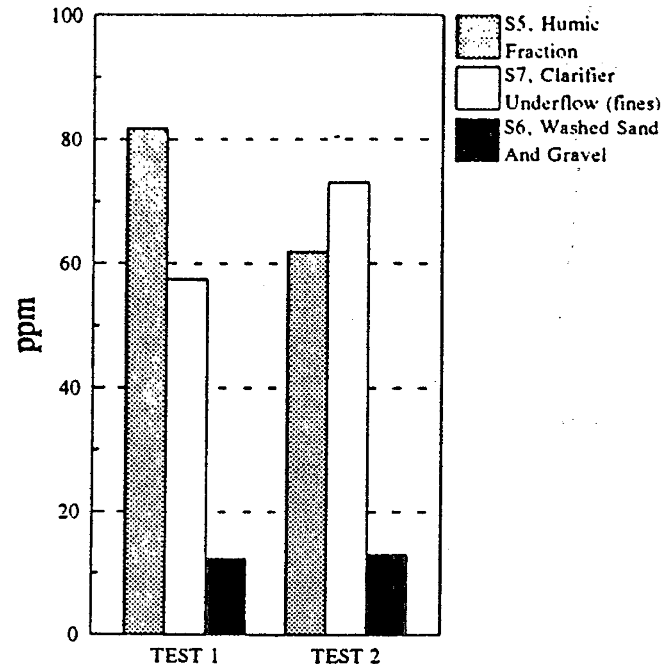


Figure 5a. Lead Concentration Distribution Data

250%. Two items suggest that the source of the imbalance is the input or "make-up" water stream. First, the amount of water measured coming into the system was approximately 2 gpm. This water constitutes the total fresh supply to the system and is used to slurry the feed sediments and to maintain adequate slurry densities throughout the sediment washing process. The amount of water entering the system must match the amount of water leaving the system via wet output product streams. Table 2 gives the water content and rate for each of the output streams for Tests 1 and 2. Clearly, the amount of water entering the system should be an order of magnitude higher. Second, Bergmann USA personnel indicated that the meter used to measure the flow of make-up water was actually calibrated for another internal process stream which has a much higher flowrate. Consequently, the water velocity within the make-up water pipe was not high enough to generate an accurate signal within the meter. Therefore, it is very probable that the amount of water entering the system was much greater than the amount measured.

The failure to achieve an adequate total mass balance has little effect on the other component balances. This can be shown by considering the solids balance. The average closure for the solids balance in Test 1 was 108 percent. The range was 101 to 115 percent. The value for Test 2 was 103 percent. The accuracy of the solids balance was

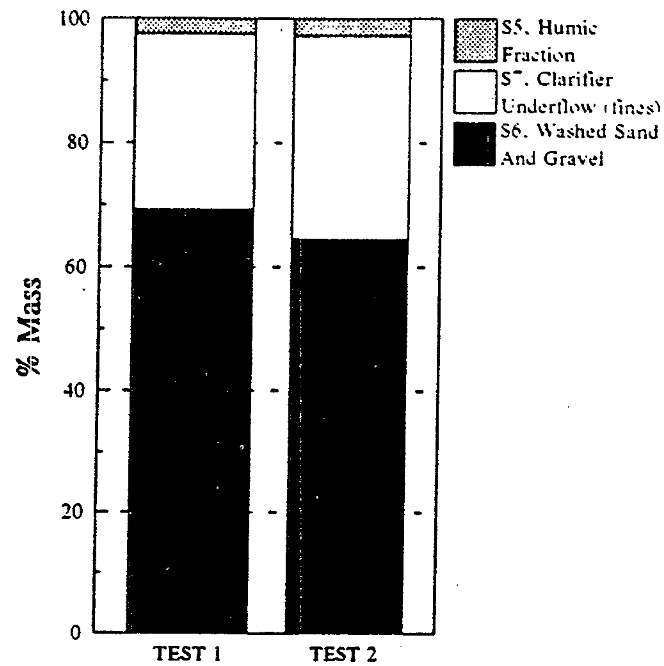


Figure 5b. Lead Mass Distribution Data

Table 2. Water Content for Tests 1 and 2

	Volume In			Volume Out	Volume Out / Volume In
	S1 (gal)	S8 (gal)	Total (gal)	S2 + S5 + S6 + S7 (gal)	Volume Balance (%)
TEST 1	1,260	1,080	2,340	14,500	619
TEST 2	1,150	1,360	2,510	13,400	534

seemingly unaffected by the incomplete measurement of the input water. This is explained by the fact that the input water carries very few solids. If it is assumed that the rate of water entering the system was approximately 28 gpm (i.e., output water rate minus water content of the dredged sediments), then the amount of solids entering the system with the make-up water should constitute fewer than 1% of the solids entering the system with the dredged sediments.

(Note: The value of performing materials balances is to ensure that there are no significant and undetected emissions from the system. Since the solids *do* balance, it may be assumed that no emissions existed.)

The fine particles (<45-microns) balance for Test 1 was an average of approximately 69.4% with a range of 53.2 to 99.4 percent. The closure for Test 2 was 66.0 percent. The variability of the balance appears to stem from the variability associated with the analysis of fines in the rotary trommel screen oversize output. The relative range of values for fines mass in the trommel oversize was higher than any other output stream (27.9 to 41.9%). This is understandable given that there is no consistent method to sieve fines that adhere to other larger particles or fines that compact with one another to form clay balls during this screening process. This wide range could also be explained by the fact that this stream is highly heterogeneous and it is possible that representative samples may not have been collected.

The PCB mass balance closure for Test 1 was 59.1 percent, with a range of 52.6 to 66.1 percent. The PCB closure for Test 2 was 51.7 percent. The accuracy of the analytical method used for the determination of PCBs was 50 to 150%. Therefore, the range of values for Test 1 suggest that PCB mass closure could be acceptible. The closure for Test 2 may indicate that a greater number of samples are required to narrow the confidence range to estimate the true mean for each of the streams (Test 1 had 32 samples, while Test 2 had only 8 samples).

The results of the mass balances for metals during the Demonstration Tests depended on the particular element of interest. For Test 1, the mass balance closure for copper was approximately 71.8% and for Test 2 the copper mass balance closure was 87.8%. On this basis, it appears that the addition of surfactant aided in the metals mass balance. However, inspection of Table 3 shows that the mass balance improved daily as testing activities proceeded. Further investigation of hypotheses of why the metals mass balance improved daily is beyond the scope of this project. All metals identified showed this distribution with the exception of aluminum and lead.

Table 4 shows the variation of the mass balance for lead for both the tests. The average mass balance for Test 1 was approximately 118%. Although Test 2 had a higher mass (poorer) balance closure, the trend shown by the other metals was not followed. That is, mass balances for lead

Table 3. Copper Mass Balance Data

	Mass In	Mass Out					Mass Out / Mass In
	S1 (g)	S2 (g)	S5 (g)	S6 (g)	S7 (g)	Total (g)	Mass Balance (%)
Test 1							
Day 1*	530	75.4	7.08	112	111	305	57.6
Day 2*	487	55.4	6.94	109	128	298	61.2
Day 3*	387	67.5	6.04	174	67.2	315	81.3
Day 4*	603	166	9.04	192	157	524	86.9
Average†	502	91.1	7.02	147	116	361	71.8
Test 2 (Day 5)*	462	139	9.21	146	111	405	87.8
Overall Avg‡ (Days 1-5)	494	101	7.46	147	115	370	74.8

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table 4. Lead Mass Balance Data

	Mass In	Mass Out					Mass Out / Mass In
	S1 (g)	S2 (g)	S5 (g)	S6 (g)	S7 (g)	Total (g)	Mass Balance (%)
Test 1							
Day 1*	317	54.7	14.6	227	61.7	358	113
Day 2*	332	35.5	5.72	212	105	358	108
Day 3*	309	54.2	5.43	234	63.7	357	116
Day 4*	381	110	5.72	234	155	506	133
Average†	319	63.7	7.87	227	96.5	395	118
Test 2 (Day 5)*	319	106	8.46	196	99.5	410	129
Overall Avg‡ (Days 1-5)	331	72.2	7.97	221	97.1	398	120

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

exceeded 100%, and progressively increased and moved further away from 100% rather than approaching it. Since the specific lead compound(s) in the soil is (are) not known, it is difficult to attribute this discrepancy to any single source.

3.4 Ranges of Site Characteristics Suitable for the Technology

3.4.1 Site Selection

The selection of sites with potential for utilization of the Bergmann USA Soil/Sediment Washing System is not restricted by the geological features of the site as the equipment may be erected within the confines of the contaminated area or placed elsewhere so that the waste can be transported to the unit. A fixed facility may be constructed to house the equipment, or the equipment may simply be operated in the open. In the case of the Demonstration Test, the equipment was mounted on a barge for treatment of material on a remote island. Usually, operation is most cost-effective if the system is erected on-site. The site should be suitable for construction with appropriate access as described below.

3.4.2 Surface, Subsurface, and Clearance Requirements

Surface requirements for the operation of the Bergmann USA Soil/Sediment Washing System include a level, graded area capable of supporting the equipment. Foundations are required to support between 85 tons (for the 5 tons/hr system) and 280 tons (for the 300 tons/hr system) of soil/sediment washing equipment, including the weight of the power supply, any ancillary equipment, and structural steel.

In most cases, subsurface preparation is not required since all treatment activities take place above the soil surface. If the feed material is to be excavated and then treated on-site, all subsurface obstacles (i.e., underground piping, cables, etc.) must be removed prior to excavation.

The site must be cleared to allow assembly and operational activities to take place. The extent of the clearing depends on the operational configuration selected. If the treatment is to take place on-site, the treatment site must be cleared to allow construction of and access to the facility. This is not an issue if the equipment is to be operated off-site, as in the case when the equipment was barge-mounted during the Demonstration Test. In any case, a cleared treatment area is required for stockpiling, storage, and loading/unloading activities. Macadam roads may be necessary to provide support for oversize and heavy equipment.

3.4.3 Topographical Characteristics

The facility site must be flat, level, and stable although complete immobility of the site is not required. That is, the location of the facility need not be on land; the technology can function in a barge-mounted configuration, and therefore may also be operated in a marine environment. However, if a clarifier or dense media separator is to be used on a barge, then site activities can only be conducted during calm weather to ensure correct operation of the clarifier and dense media separator. Elevation with respect to sea level need not be a consideration. The topographical setting will not have a consequential impact on the accessibility of electrical power since the system is equipped to operate using a generator. However, an abundant water supply must be readily available and easily accessible. The water need not be potable, however, it must be free of debris. Water streams containing debris may still be used with the addition of a basket filter to the pumping system. To eliminate the cost of purchasing water from the local utility company, the water may be obtained from a nearby source such as a river or lake, if feasible, or a well may be drilled to provide water for use by the system.

3.4.4 Site Area Requirements

The site requires sufficient surface area for soil/sediment washing equipment measuring approximately 65 feet × 20 feet for the 5 tons/hr unit and up to 120 feet × 100 feet for the 300 tons/hr unit. Both structures also extend 45 feet vertically. Depending on the scale of the system selected and its location, a concrete pad may or may not be required prior to assembly. A pad will most likely be required for any system set up as a fixed facility. Additional space must be available for storage of stockpiled feed and any waste generated during the treatment process. All equipment should be situated in a manner to facilitate convenient access.

3.4.5 Climate Characteristics

For outdoor operations, climate characteristics suitable for this treatment technology include a moderate temperature range and low wind conditions. Temperatures below freezing would have a profound effect on the operation of the system since the Bergmann USA Soil/Sediment Washing System utilizes large amounts of water to "wash" the soil. Windy conditions may be detrimental to the conveyor belts and the 45-foot tower that houses the separators and other pieces of equipment. Windy conditions also make barge-mounted activities very difficult due to rough waters and wave motion. Severe storms may result in hazardous operating conditions, if the equipment is erected outdoors as it is fully exposed to the weather. The tower, often standing alone or standing taller than surrounding structures, provides a ready pathway for lightning.

To diminish the effect of many climactic attributes, the system may be erected in an enclosure. This may be a fixed structure, or this may be a tent covering the system as was the case during operation at Toronto Harbour (see Appendix D). Steam lines may be used to maintain an acceptable operating temperature within the enclosure and alleviate problems associated with freezing temperatures.

3.4.6 Geological Characteristics

Major geological constraints that can render a site unsuitable for the soil/sediment washing technology include landslide potential, volcanic activity, and fragile geological formations that may be disturbed by heavy loads or vibrational stress.

3.4.7 Utility Requirements

The utility requirements for the Bergmann USA Soil/Sediment Washing System include electricity and water. The system is equipped to operate using a generator to supply electrical power. Otherwise, a 3-phase power supply from the local electric company is required. The 5 tons/hr system pulls approximately 150 kW during operation. This requirement is increased to 2,200 kW for the 300 tons/hr system.

Water requirements include an available supply of water sufficient to fill the 5 tons/hr system with 10,000 gallons initially, and then provide approximately 30 gpm; the 300 tons/hr unit requires 15,000 gallons of water initially, then approximately 480 gpm during operation. Although the system actually requires quantities of water much greater than these specified parameters, a large amount of water is recirculated through the system, thereby reducing water usage through recycling. As discussed under "Topographical Characteristics" earlier in this section, non-potable water is acceptable for use and may be obtained from a nearby lake, river, or well.

3.4.8 Size of Operation

The capacity of the Bergmann USA Soil/Sediment Washing System utilized during the Demonstration Test was 5 tons/hr feed soil input (pilot-scale). Larger systems are also available in a wide range of sizes. Full-scale systems are identified as those processing more than 20 tons/hr.

Currently the largest system operated by Bergmann USA can process up to 300 tons/hr.

The size of the facility itself is governed by the size of the system chosen and the selection of indoor or outdoor construction and assembly (see "Site Area Requirements"). The equipment layout is slightly restricted when operating in an enclosure. In this case, overhead height becomes an issue and some modifications may be required to alter the configuration of the system to reduce the height of the tower. With no overhead restrictions, Bergmann USA utilizes gravity to aid in moving the feed throughout the system.

3.5 *Applicable Wastes*

The Bergmann USA Soil/Sediment Washing System can be used to treat both land-based soils as well as river and harbor sediments. The contaminated soil or sediment should contain no more than about 40% silt and clay material smaller than 45 micron. Solid organic content should not exceed 20% by volume. The organic content is specified in terms of volume because of the low specific gravity of this media in relation to the other components of the soil/sediment. The medium to be separated may be contaminated with both organic and inorganic constituents. Typical contaminant groups that can be effectively isolated and concentrated include: petroleum and fuel residues, radioactive contaminants, heavy metals, PCBs, creosote, pentachlorophenols (PCPs), pesticides, and cyanides.

Materials handling requirements for operation of a Bergmann USA Soil/Sediment Washing System include containerization of the process feed and transport of this material to the facility. Depending on the hazard and volatility of the waste, containerization may entail the use of small sealed containers such as 55-gallon drums or perhaps larger vessels such as the holds of dredging barges for dredged lake or river sediments. The use of small containers is not likely since treatment will most often take place on-site, except when dredged sediments are being processed. Containerization of the concentrated solid wastes (fines and humic fraction) and possibly the liquid waste (clarifier underflow) must also be considered along with transport of these residues and effluents for disposal. Since the process isolates and concentrates contaminants into the fines and the humic fraction, these residues (a reduced volume of contaminated waste) and the effluent may require additional treatment prior to final disposal.

3.6 *Regulatory Requirements*

Operation of the Bergmann USA Soil/Sediment Washing System for pre-treatment of contaminated soil requires compliance with certain Federal, state, and local regulatory standards and guidelines. Section 121 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requires that, subject to specified exceptions, remedial actions must be undertaken in compliance with Applicable or Relevant and Appropriate Requirements (ARARs), Federal laws, and more stringent state laws (in response to releases or threats of releases of hazardous substances, pollutants, or contaminants) as necessary to protect human health and the environment.

The ARARs that must be followed in treating Superfund waste on-site are outlined in the Interim Guidance on Compliance with ARARs, Federal Register, Vol. 52, pp. 32496 et seq. These are:

- Performance, Design, or Action-Specific Requirements. Examples include RCRA incineration standards and Clean Water Act (CWA) pretreatment standards for discharge to Publicly Owned Treatment Works (POTWs). These requirements are triggered by the particular remedial activity selected to clean a site.

- Ambient/Chemical-Specific Requirements. These set health-risk-based concentration limits based on pollutants and contaminants, e.g., emission limits and ambient air quality standards. The most stringent ARAR must be complied with.

- Locational Requirements. These set restrictions on activities because of site location and environs.

Deployment of the Bergmann USA system will be affected by three main levels of regulation:

- USEPA air and water pollution regulations,

- State air and water pollution regulations, and

- Local regulations, particularly Air Quality Management District (AQMD) requirements.

These regulations govern the operation of all technologies. Other Federal, state, and local regulations are discussed in detail below as they apply to the performance, emissions, and residues evaluated from measurements taken during the Demonstration Test.

3.6.1 Federal USEPA Regulations

3.6.1.1 Clean Air Act

The Clean Air Act (CAA) establishes primary and secondary ambient air quality standards for protection of public health, and emission limitations for certain hazardous air pollutants. Permitting requirements under the Clean Air Act are administered by each state as part of State Implementation Plans developed to bring each state into compliance with National Ambient Air Quality Standards (NAAQS). The ambient air quality standards listed for specific pollutants may be applicable to operation of the Bergmann USA system due to its potential emissions when processing volatile compounds. Therefore, when volatile organic compounds are present in the feed, an air pollution control device, including a carbon bed or comparable means, must be utilized for cleanup of these compounds. Other regulated emissions may also be produced, depending on the waste feed. A Bergmann USA Soil/Sediment Washing System built in any state may be required to obtain an air permit. The allowable emissions will be established on a case-by-case basis depending upon whether or not the site is in attainment of the NAAQS. If the area is in attainment, the allowable emission limits may still be curtailed by the available increments under Prevention of Significant Deterioration (PSD) regulations. This can only be determined on a site-by-site basis.

3.6.1.2 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for Federal funding to respond to releases of hazardous substances to air, water, and land. Section 121 of SARA, entitled Cleanup Standards, states a strong statutory preference for remedies that are highly reliable and provide long-term protection. It strongly recommends that remedial actions use on-site treatment that "...permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances." In addition, general factors which must be addressed by CERCLA remedial actions are:

- long-term effectiveness and permanence,
- short-term effectiveness,
- implementability, and
- cost.

The Bergmann USA system has demonstrated that contaminants in the feed stream can be concentrated and isolated by separating soil and sediment particles according to grain size and density. Although this does not totally eliminate the contamination from any particular waste feed material, it does reduce the quantity of significantly contaminated material and separates the feed into streams with levels of contamination ranging from insignificant to serious. This illustrates both long-term and, especially, short-term effectiveness. In the immediate future, it reduces the amount of contaminated material; in the long run, the technology reduces the amount of contaminated waste requiring treatment and subsequent landfill.

The short-term effectiveness of the Bergmann USA system may be evaluated by examining analytical data obtained from the various waste streams. The data indicate that the contaminants present in the feed (i.e., PCBs and metals for the Demonstration Test) were concentrated in two solid streams, the fines and the humic fraction. These waste streams may require treatment and must be disposed of properly. For the Demonstration Test, levels of contamination in both the solid streams and the liquid streams were below regulated levels. This implies that, in most cases (with the exception of "derived from" wastes which are considered listed wastes regardless of their final levels of contamination), these secondary waste streams may be disposed of in a licensed landfill without the need for additional treatment.

The implementability of the system appears favorable. The 5 tons/hr system is relatively mobile and easily assembled. The ease of mobility decreases with larger scale systems, indicating that larger scale systems may be better suited to fixed facilities where ongoing treatment is required rather than for facilities where short-term treatment is required.

Based on the Economic Analysis of the Bergmann USA system (see Section 4), the cost of this technology is a competitive means of pre-treating contaminated material. Although soil/sediment washing concentrates the level of contamination, it also isolates the contamination, and therefore, use of this technology reduces the amount of contaminated material requiring treatment prior to disposal.

3.6.1.3 Resource Conservation and Recovery Act (RCRA)

The Resource Conservation and Recovery Act is the primary Federal legislation governing hazardous waste activities. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are also applicable to CERCLA activities.

Depending on the waste feed and the effectiveness of the treatment process, the Bergmann USA system may generate several hazardous waste streams: the fines (material less than 45 microns in size), the humic fraction (twigs, leaves, bark, etc.), and potentially the clarifier underflow. These streams contain the concentrated contaminants which have been washed from the feed material and isolated from the other streams.

For generation of any hazardous waste, the site responsible party must obtain a USEPA identification number and comply with accumulation requirements for generators under 40 CFR 262 or have been granted interim status, or issued a hazardous waste facility permit for the treatment and storage activities. Compliance with RCRA is required for CERCLA sites. A hazardous waste manifest must accompany any off-site shipment of waste. Transport must comply with Federal Department of Transportation (DOT) hazardous waste transportation regulations. The receiving Treatment, Storage, and Disposal (TSD) facility must be permitted and in compliance with RCRA standards.

Technology or treatment standards have been established for many hazardous wastes; those appropriate for the Bergmann USA process will be determined by the type of waste generated. The RCRA land disposal restriction regulations, found in 40 CFR 268, mandate that hazardous wastes that do not meet the required treatment standards receive treatment after removal from a contaminated site and prior to land disposal, unless a variance is granted. If the fines, the humic fraction, or the clarifier underflow are hazardous wastes that do not meet their pertinent treatment standards (a likely scenario for the solid streams), treatment will be required prior to land disposal. Incineration may be the Best Demonstrated Available Treatment (BDAT) prior to disposal of any solid residue in a certified landfill. Precipitation and/or carbon adsorption may be necessary for any waste clarifier underflow.

3.6.1.4 Toxic Substances Control Act (TSCA)

The Toxic Substances Control Act (TSCA) grants the USEPA the authority to prohibit or control the manufacturing, importing, processing, use, and disposal of any chemical substance that presents an unreasonable risk of injury to human health or the environment. These regulations may be found in 40 CFR 761. With respect to hazardous waste regulation, TSCA focuses on the use, management, disposal, and cleanup of PCBs. Materials with <50 ppm PCB are classified as non-PCB; those containing PCB between 50 and 500 ppm are classified as PCB-contaminated; and those with 500 ppm or greater PCB are classified as PCB.

The waste feed used for this Demonstration of the Bergmann USA Soil/Sediment Washing System contained an overall average level of 1.35 ppm PCBs. The levels of PCBs in some of the output streams were elevated as a result of the separation process. The humic fraction contained an overall average of approximately 11.0 ppm and the concentrated fines from the clarifier underflow contained approximately 4.42 ppm. However, even the stream with the highest levels of PCBs was below the TSCA limit for PCB-contaminated material by a factor of 4.

3.6.1.5 Clean Water Act (CWA)

The Clean Water Act regulates direct discharges to surface water through the National Pollutant Discharge Elimination System (NPDES) regulations. These regulations require point-source discharges of wastewater to meet established water quality standards. Typical operation of the Bergmann USA system generates one liquid discharge stream, the clarifier underflow. All other liquid streams are recycled throughout the system. Unless the feed material contains soluble contaminants, it is anticipated that this overflow will be discharged into the sanitary sewer. Discharge of wastewater to the sanitary sewer requires a discharge permit or, at least, concurrence from state and local regulatory authorities that the wastewater is in compliance with regulatory limits. The wastewater may contain flocculants, surfactants, or other water conditioners at unregulated levels.

3.6.1.6 Safe Drinking Water Act (SDWA)

The Safe Drinking Water Act establishes primary and secondary national drinking water standards. Provisions of the Safe Drinking Water Act apply to remediation of Superfund sites. CERCLA Sections 121(d)(2)(A) and (B) explicitly mention three kinds of surface water or groundwater standards with which compliance is potentially required - Maximum Contaminant Level Goals (MCLGs), Federal Water Quality Criteria (FWQC), and Alternate Concentration Limits (ACLs) where human exposure is to be limited. CERCLA describes those requirements and how they may be applied to Superfund remedial actions. The guidance is based on Federal requirements and policies; more stringent, state requirements may result in application of even stricter standards than those specified in Federal regulations. The Bergmann USA system generates one liquid discharge stream, the clarifier overflow. Although anticipated to be nonhazardous, this stream must meet the above described standards as applicable for each particular operation.

3.6.2 State and Local Regulations

Compliance with ARARs may require meeting state standards that are more stringent than Federal standards or may be the controlling standards in the case of non-CERCLA treatment activities. Several types of state and local regulations that may affect operation of the Bergmann USA system are cited below:

- permitting requirements for construction/operation,
- prohibitions on emission levels, and
- nuisance rules.

3.7 Personnel Issues

3.7.1 Operator Training

Operator training specific to the Bergmann USA system is required, particularly for all local hires. Other workers, such as supervisors and lead operators, are Bergmann USA employees already intimately familiar with the system. These employees will perform on-line training of the local hires. This is necessary in order to develop a safe and effective operating technique for this technology.

3.7.2 Health and Safety

The U.S. Department of Labor (USDOL) specifies occupational health and safety standards for general industry in 29 CFR 1910. Within these regulations are detailed sections applying to occupation protection of employees at hazardous waste treatment sites. Health and safety regulations for construction are specified by the USDOL in 29 CFR 1926. The health and safety issues involved in using the Bergmann USA system for waste treatment include those presented in the above mentioned regulations. Additional issues are generally the same as those that apply to all hazardous waste treatment facilities as detailed in 40 CFR 264 Subparts B through G, and Subpart X. It should be noted that the SITE Demonstration Tests did not take place at a hazardous waste treatment site, and accordingly, hazardous waste treatment rules, neither USEPA (40 CFR) nor USDOL (26 CFR) apply.

The principal occupational hazard of the Bergmann USA Soil/Sediment Washing System is probably not the health risk from exposure to toxic substances (except in extreme cases), but rather the risk of injury. Although it poses no significant threat of explosion, fire, etc., the Bergmann USA system is comprised of equipment with great heights, moving machinery, high voltage, pinch points, conveyor belts, and other safety hazards. Therefore, the physical hazards may be greater than the chemical hazards depending on the waste.

3.7.3 Emergency Response

The emergency response training for using the Bergmann USA system is the same general training required for operating a TSD facility as detailed in 40 CFR 264 Subpart D. Training must address fire and containment-related issues such as extinguisher operation, hoses, sprinklers, hydrants, smoke detectors and alarm systems, self-contained breathing apparatus use, hazardous material spill control and decontamination equipment use, evacuation, emergency response planning, and coordination with outside emergency personnel (e.g., fire/ambulance).

3.8 Summary

The Bergmann USA Soil/Sediment Washing System evaluated during the SITE Demonstration activities consisted of a number of different proven technologies used in the mineral processing industry to successfully separate the contaminant-rich fines from the washed coarse fraction. For the purposes of the SITE Demonstration, the gravity and size separation technologies employed with a countercurrent washwater mode of operation was sufficient to isolate and concentrate the contaminants effectively. However, the soil/sediment washer could have also been used in the cocurrent mode or with any of the individual technologies taken out of the system. The effectiveness of the washer in different modes of operation was the subject of the USACE testing. Surfactant was successfully used during the Demonstration activities. Because of the nature of the feed, the surfactant had no effect on the performance of the technology. However, the Demonstration Test did show that surfactant could be used by the system without disrupting operations.

Bergmann USA manufactures a variety of technologies for use in separating contaminated soils and sediments into clean and concentrated fractions. These technologies are then assembled into a soil/sediment washing system dependent on the soil type and the form of contamination. Different assemblies of these other technologies have not been subject to evaluation under the SITE Demonstration Program.

The soil/sediment washing systems are available in sizes ranging from pilot-scale at 5 tons/hr to full-scale at 300 tons/hr. Obviously, the size of unit selected for a particular site is dependent on the volume of soil/sediment required to be separated.

The effectiveness of the Bergmann USA Soil/Sediment Washing System (or any other aqueous based soil washing system) for the distribution of water soluble compounds is affected by the moisture content of the output streams. However, if the water can be easily separated from the output, then this water can undergo secondary treatment prior to disposal.

The sediment used for the feed during the Demonstration Testing did not contain volatile compounds. In other cases, however, if volatile compounds are present in the feed soil, precautions must be taken to ensure that fugitive emissions do not exceed ambient air quality standards. This may include housing the system in an enclosure and passing all the local air through activated carbon or some other collection or destructive technique. If water soluble compounds are present in the feed soil, then the washwater from the process may require treatment before discharge of the water to a sanitary sewer is permitted.

As with any remediation technology, before this system can be implemented or a Record of Decision is approved for a particular hazardous waste site, treatability studies must be performed. The treatability studies will enable the correct selection and configuration of the separation modules to be employed if this technology is suitable for remediation of that site.

Section 4

Economic Analysis

4.1 Introduction

The primary purpose of this economic analysis is to estimate costs (not including profits) for a commercial-size treatment utilizing the Bergmann USA Soil/Sediment Washing System. The soil/sediment washer used during the Demonstration Test was a small pilot-scale unit (feed rate of 5 tons/hr). This economic analysis investigates systems ranging from 5 to 100 tons/hr. The costs associated with the Bergmann USA Soil/Sediment Washing System, as presented in this economic analysis, are defined by 12 cost categories that reflect typical cleanup activities encountered on Superfund sites. Each of these cleanup activities is defined and discussed, forming the basis for the estimated cost analysis presented in Tables 5 and 6. The costs presented are based upon installing and operating the Bergmann USA Soil/Sediment Washing System at a facility for a period of 12 months.

The actual Demonstration Test treated approximately 144 tons of contaminated soil and sediments at a feed rate of approximately 4 tons/hr with an on-line percentage of 100%. However, the system is rated at 5 tons/hr and this rate provides the basis for this economic analysis. Since the Bergmann USA Soil/Sediment Washing System used during the Demonstration Tests was pilot-scale, and not as cost-effective as a full-scale unit, cost calculations were also performed for other existing Bergmann USA Soil/Sediment Washing Systems treating 15, 25, and 100 tons/hr. The costs for the system used during the Demonstration Test are presented in Table 5 and are based on:

- a feed rate of 5 tons/hr;
- an on-line percentage of 90%; and
- an operating time of 14 hrs/day and 5 days/wk;
- and a treatment time of 12 months.

The on-line percentage takes into account periodic shutdowns to respond to maintenance or operational problems. Although 100% on-line conditions cannot be expected during extended periods of operating time, it is common practice in the sand and gravel industry to achieve an on-line factor as high as 90 to 95%. For the purposes of this evaluation an on-line factor of 90% is assumed.

Table 6 shows the costs for Bergmann USA Soil/Sediment Washing Systems operating with feed rates of 5, 15, 25, and 100 tons/hr and 90% on-line conditions. The cost estimates presented in Table 6 are based on the same assumptions listed for Table 5 with the exception of the feed rate and the associated project duration which vary for each case (see Table 6).

Costs which are assumed to be the obligation of the responsible party or site owner have been omitted from this cost estimate and are indicated by a line (---) on Tables 5 and 6. Categories with no costs associated with this technology are indicated by a zero (0) on Tables 5 and 6.

Important assumptions regarding operating conditions and task responsibilities that could significantly impact the cost estimate results are presented below.

The cost estimates presented in this analysis are representative of charges typically assessed to the client by the vendor and do not include profit. Costs such as preliminary site preparation, permits and regulatory requirements, initiation of monitoring programs, waste disposal, sampling and analysis, and site cleanup and restoration are considered to be the responsible party's (or site owner's) obligation and are not included in the estimate presented. Although not necessarily assessed by the vendor, costs for excavation *are* included in this estimate since excavation of the waste feed is always required. The costs mentioned above tend to be site-specific and in most cases the calculations are left for the reader to perform in a manner relevant to his specific case. Whenever possible, applicable information on these topics is provided to assist the reader in these calculations.

For hypothetical 100% on-line conditions, the treatment rate is the same as the feed rate of the Bergmann USA Soil/Sediment Washing System. Generally, two factors

Table 5. Estimated Costs in $/Ton of the Bergmann USA Pilot-Scale Soil/Sediment Washing System[#,*]
Feed Rate = 5 tons/hr
On-line Percentage = 90%
Total Treatment Time = 12 months

Site and Facility Preparation Costs	
Site design and layout	---
Survey and site investigations	---
Legal searches	---
Access rights and roads	---
Preparations for support facilities	---
Utility connections	---
Auxiliary buildings	---
Installation of major equipment	$0.28
Technology-specific requirements	$19.75**
Transportation of waste feed	---
Total Site and Facility Preparation Costs	**$20.03**
Permitting and Regulatory Costs	
Permits	---
System monitoring requirements	---
Development of monitoring and protocols	---
Total Permitting and Regulatory Costs	---
Equipment Costs	
Major equipment†	$74.07†
Annualized equipment cost	$9.06
Equipment rental	$3.67
Total Equipment Costs	**$12.73**
Startup and Fixed Costs	
On-line operation training	$1.47
Waste-specific equipment testing	$0.59
Working capital	$12.01
Insurance and taxes	$7.41
Initiation of monitoring programs	---
Contingency	$7.41
Total Startup and Fixed Costs	**$28.89**
Labor Costs	
Supervisors	$18.89
Lead Operators	$16.35
Feed operators	$7.62
Maintenance operators	$15.24
Total Labor Costs	**$58.10**
Supplies Costs	
Surfactant	$1.00
Flocculent	$0.92
Miscellaneous	$6.00
Total Supplies Costs	**$7.92**
Consumables Costs	
Fuel	$0.67
Water	$0.67
Electricity	$2.76
Total Consumables Costs	**$4.10**
Effluent Treatment and Disposal Costs	
On-site facility costs	---
Off-site facility costs	---
-wastewater disposal	---
-monitoring activities	0
Total Effluent Treatment and Disposal Costs	**0**

Table 5. Estimated Costs in $/Ton of the Bergmann USA Pilot-Scale Soil/Sediment Washing System#,* (cont.)

Residuals & Waste Shipping, Handling & Transport Costs	
Preparation	---
Waste disposal	---
Total Residuals & Waste Shipping, Handling & Transport Costs	---
Analytical Costs	
Operations	$19.05
Environmental monitoring	---
Total Analytical Costs	**$19.05**
Facility Modification, Repair, & Replacement Costs	
Design adjustments	0
Facility modifications	0
Scheduled maintenance (materials)	$0.54
Equipment replacement	0
Total Facility Modification, Repair, & Replacement Costs	**$0.54**
Site Restoration Costs	
Site cleanup and restoration	---
Permanent storage	---
Total Site Restoration Costs	**0**
TOTAL OPERATING COSTS ($/TON)	**$151.35**
[TOTAL OPERATING COSTS EXCLUDING EXCAVATION ($/TON)]	**($131.60)**

All costs estimated at 1993 prices.

* Costs for treating waste at 5 tons/hr for 12 months. Refer to Section 4.3 for information on how the costs in this table were determined.

** Excavation costs may not be assessed by the vendor. They are included here because the waste feed must be excavated prior to treatment. Total operating costs exclusive of excavation are presented for comparison at the end of the table.

† This cost is reported in "$", not "$/ton". It is not used directly, but is used for estimating other costs (i.e., annualized equipment cost, insurance and taxes, scheduled maintenance, and contingency).

limit the treatment rate: the feed rate and the on-line percentage.

All operations are assumed to be 14 hours a day, five days a week. Two shifts of working crews are required each day. Each shift is assumed to be 8 hours. On-line training of local hires is assumed to be conducted 8 hours a day for 13 days. Excavation activities for site preparation will take place concurrent with treatment and are assumed to be 16 hours a day, five days a week. Assembly is assumed to require four 14-hour days. Waste-specific equipment testing will occur before treatment is begun and is assumed to require three 14-hour days.

Transportation costs of the waste feed from a waste site to the Bergmann USA Soil/Sediment Washing System are site- and waste-specific, and have not been included in these cost calculations.

Operations for a typical shift require 5 workers: 1 supervisor, 1 lead operator, 1 feed operator, and 2 maintenance operators.

Capital costs for equipment are not used directly, and are limited to the cost of the Soil/Sediment Washing System. Percentages of the total equipment cost are used for estimating purposes.

Many actual or potential costs that exist were not included as part of this estimate. They were omitted because site-specific engineering designs that are beyond the scope of this SITE project would be required. Certain functions

Table 6. Costs in $/Ton for Operation of Various Sizes of Bergmann USA Soil/Sediment Washing Systems*

Treatment Rate	5 Tons/Hr	15 Tons/Hr	25 Tons/Hr	100 Tons/Hr
Total Treatment Time	1 Year	2 Years	3 Years	5 Years
Total Volume Treated	16,200 Tons	97,200 Tons	243,000 Tons	1,620,000 Tons
Site Facility Preparation Costs including excavation (excluding excavation)	$20.03 ($0.28)	$17.86 ($0.10)	$15.79 ($0.07)	$14.76 ($0.05)
Permitting & Regulatory Costs	---	---	---	---
Equipment Costs	$12.73	$8.51	$7.29	$5.04
Startup & Fixed Costs	$28.89	$19.64	$16.86	$11.12
Labor Costs	$58.10	$19.37	$11.62	$3.67
Supplies Costs	$7.92	$6.67	$5.42	$4.12
Consumables Costs	$4.10	$2.72	$3.00	$2.35
Effluent Treatment & Disposal Costs	---	---	---	---
Residuals & Waste Shipping, Handling, & Transport Costs	---	---	---	---
Analytical Costs	$19.05	$6.35	$3.81	$0.95
Facility Modifications, Repair, & Replacement Costs	$0.54	$0.36	$0.30	$0.17
Site Restoration Costs	---	---	---	---
Total Costs	$151.36	$81.48	$64.09	$42.18
(Total Costs excluding excavation)	($131.61)	($63.72)	($48.37)	($27.47)

* All costs estimated at 1993 prices.

were assumed to be the obligation of the responsible party or site owner and were not included in the estimates.

4.2 *Results of Economic Analysis*

Data gathered during the Demonstration Test indicates that the on-line factor of the Bergmann USA Soil/Sediment Washing System was 100%. However, in order to account for scheduled and unscheduled maintenance, a 90% on-line factor was assumed. Other data indicates that this is typical of more extensive (longer) operations of the Bergmann USA Soil/Sediment Washing System, therefore, all calculations were performed based on a 90% on-line factor. The feed rate during the Demonstration Test was approximately 4 tons/hr, but since the unit was sized for 5 tons/hr, this higher feed rate has been assumed for the cost estimate. For a feed rate of 5 tons/hr and a total treatment time of 12 months, the results of the analysis show a cost-per-ton estimate of $151 for 90% on-line conditions. These costs are considered to be order-of-magnitude estimates as defined by the American Association of Cost Engineers, with an expected accuracy within +50% and -30%. Since the 5 tons/hr Bergmann USA Soil/Sediment Washing System is at the pilot-scale level, the cost per ton of soil treated is relatively high. For other larger units with higher feed rates and the same 90% on-line factor, the cost per ton is less: $81 and $63 for the 15 and 25 tons/hr units, respectively. For the 100 tons/hr unit, the cost per ton drops to $42 for 90% on-line conditions.

Figure 6 presents the costs for each of the twelve cost categories for feed rates of 5 tons/hr. Figure 7 presents the relative treatment cost of Bergmann USA Soil/Sediment Washing Systems operating at feed rates of 5 to 100 tons/hr and 90% on-line conditions.

The results show that, in each case, site facility preparation costs (including excavation) make up a large portion of the costs ranging from 13% for the 5 tons/hr unit up to 35% for the 100 tons/hr unit. The results also indicate that, for lower feed rates, labor is a cost primary factor. For higher feed rates, the impact of labor costs decreases. For example, with a feed rate of 5 tons/hr, approximately 38% of the total cost can be attributed to labor; with a feed rate of 100 tons/hr, labor costs are reduced to approximately 9% of the total cost. Startup and fixed costs are another important factor, becoming more dominant with higher feed rates. The startup and fixed costs of the full-scale Bergmann USA Soil/Sediment Washing System operating at 100 tons/hr make up approximately 26% of the total cost Together, labor and startup and fixed costs make up 58%, 48%, 44%, and 35% of the total operating cost of a Bergmann USA Soil/Sediment Washing System operating at 5, 15, 25, and 100 tons/hr, respectively. Ordinarily, these costs can be reduced by increasing the on-line percentage and feed rate, thus increasing the actual treatment rate and decreasing the treatment time required. In this case, since the on-line percentage is already so high, it is unlikely that this factor may be improved.

4.3 *Basis for Economic Analysis*

The cost analysis was prepared by breaking down the overall cost into 12 categories:

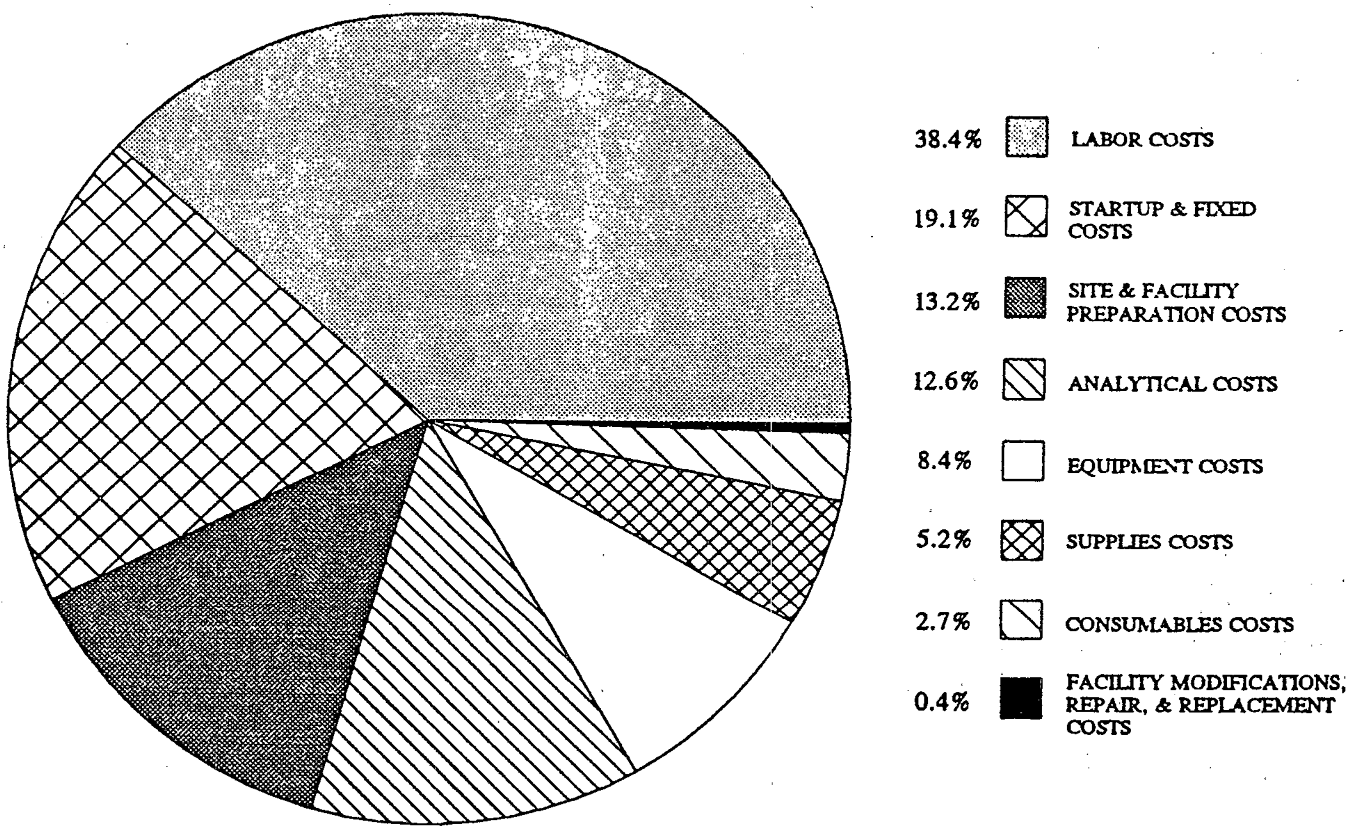
- Site and facility preparation costs,
- Permitting and regulatory costs,
- Equipment costs,
- Startup and fixed costs,
- Labor costs,
- Supplies costs,
- Consumables costs,
- Effluent treatment and disposal costs,
- Residuals and waste shipping, handling, and transport costs,
- Analytical costs,
- Facility modification, repair, and replacement costs, and
- Site restoration costs.

The 12 cost factors examined as they apply to the Bergmann USA process, along with the assumptions employed, are described in detail below. Except where specified, the same assumptions were made for the costs of operating a Bergmann USA Soil/Sediment Washing System at 5, 15, 25, and 100 tons/hr.

4.3.1 Site and Facility Preparation Costs

For the purposes of these cost calculations, "site" refers to the location of the contaminated waste and "facility" refers to the location where the Bergmann USA Soil/Sediment Washing System is operated. In many cases, the waste must be transported from the site to the facility.

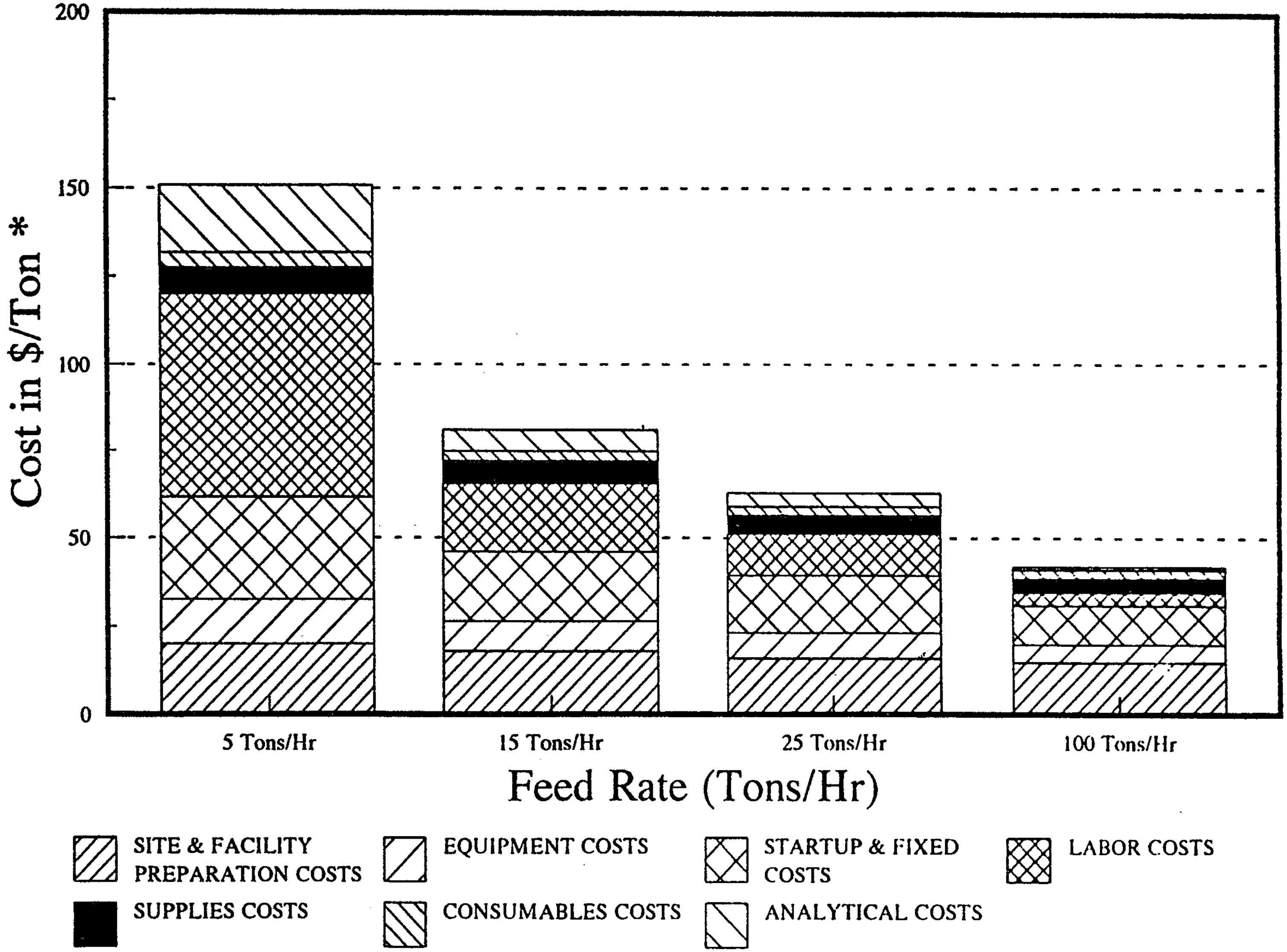
Breakdown of Costs for Feed Rate of 5 Tons/Hr *



Refer to Table 5 for additional information on these cost categories

Figure 6. Summary of Cost Categories for 5 Tons/Hr Unit. *

* Permitting & Regulatory Costs; Effluent Treatment & Disposal Costs; Residuals & Waste Shipping, Handling, & Transport Costs; and Site Restoration Costs each sum to less than $1/Ton.



Refer to Table 6 for additional information on these cost categories

Figure 7. Summary of Overall Treatment Costs of Bergmann USA Soil/Sediment Washing Systems. *

* Permitting & Regulatory Costs; Effluent Treatment & Disposal Costs; Residuals & Waste Shipping, Handling, & Transport Costs; Facility Modifications, Repair, & Replacement Costs; and Site Restoration Costs each sum to less than $1/Ton.

* Permitting & Regulatory Costs; Effluent Treatment & Disposal Costs; Residuals & Waste Shipping, Handling, & Transport Costs; Facility Modifications, Repair, & Replacement Costs; and Site Restoration Costs each sum to less than $1/ton.

Refer to Table 6 for additional information on these cost categories.

It is assumed that preliminary site preparation will be performed by the responsible party (or site owner). The amount of preliminary site preparation will depend on the site. Site preparation responsibilities include site design and layout, surveys and site logistics, legal searches, access rights and roads, preparations for support and decontamination facilities, utility connections, and auxiliary buildings. Since these costs are site-specific, they are not included as part of the site preparation costs in this estimate.

Additional site preparation requirements peculiar to the Bergmann USA Soil/Sediment Washing System are assumed to be performed by the prime contractor. These site preparation activities include excavation of hazardous waste from the contaminated site and storing the waste in appropriate containers prior to treatment. The costs for excavation are included in this cost estimate because the waste must always be excavated prior to treatment.

Cost estimates for site preparation should be based on operated heavy equipment rental costs, labor charges, and equipment fuel costs. Excavation activities are assumed to take place 16 hours a day, 5 days a week. To achieve an excavation rate of approximately 10 tons/hr, it may be assumed that the minimum rental equipment required is: three excavators, one box dump truck, and one backhoe. Estimated equipment rental rates and terms vary with individual rental companies. An excavator is available for approximately $2,800/mo, a box dump truck is available for approximately $1,500/mo, and a backhoe is available for approximately $2,000/mo. The minimum labor required is one supervisor at $40/hr, three excavator operators at $30/hr each, one box dump truck operator at $30/hr, and one backhoe operator at $30/hr. Diesel fuel consumption is estimated at 3 gals/hr/excavator, 2 gals/hr/box dump truck, and 3 gals/hr/backhoe. Diesel fuel prices fluctuate with supply and demand and current market prices; however, for these calculations it is assumed to be $1/gal.

Transportation costs of the contaminated waste from the site to the Bergmann USA Soil/Sediment Washing System are very site- and waste-specific and have not been included in these cost calculations.

For the purposes of these cost calculations, installation costs are limited to transportation and assembly costs of the Bergmann USA Soil/Sediment Washing System. The installation cost has been annualized based on a 10-year life of the equipment and a 6% annual interest rate. The annualized installation cost is based on the writeoff of the total installation cost, using the following equation:

$$\text{Annualized Installation Cost} = (V)\,\frac{i(1+i)^n}{(1+i)^n - 1}$$

Where V is the cost of installation (assumed to be limited to transportation and assembly costs),

n is the equipment life (10 years), and

i is the annual interest rate (6%).

Transportation costs to convey the system to the facility are limited to trucking costs. Trucking charges include drivers and are based on a 40,000 pound, 48-foot long, 8-foot high legal load. Ten tractor/trailers are required to transport the 5 tons/hr Bergmann USA Soil/Sediment Washing System; 12, 15, and 30 trailers are required to transport the larger Bergmann USA Soil/Sediment Washing Systems (15, 25, and 100 tons/hr, respectively). A 1,000-mile basis is assumed at a rate of $1.65/mile/legal load.

Assembly consists of unloading the Bergmann USA Soil/Sediment Washing System from the trailers, assembling the system and conducting shakedown testing to check out each of the individual subsystems. Assembly costs are limited to a 40 ton crane rental charge, and labor charges. Estimated rental rates for a 40 ton crane with an 8-foot boom are $150/hr. The crane is required 8 hours/day for 3 days for the 5 tons/hr, 15 tons/hr , and 25 tons/hr systems. The crane is required for 5 days for the 100 tons/hr system. For 4 days, 2 shifts of 5 workers are required for 16 hours a day (total) during the assembly activities. See "Labor Costs," Section 4.3.5.

Utility connections and auxiliary buildings necessary for the Bergmann USA Soil/Sediment Washing System to operate at a fixed facility can be very expensive. These costs depend on the fixed facility, and must be considered in site-specific cost calculations.

4.3.2 Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner), not that of the vendor. These costs may include actual permit costs, system monitoring requirements, and the development of monitoring and analytical protocols. Permitting and regulatory costs can vary greatly because they are site- and waste-specific. No permitting costs are included in this analysis, however depending on the treatment site, this may be a significant factor since permitting activities can be very expensive and time-consuming.

4.3.3 Equipment Costs

Equipment costs include major pieces of equipment (attrition scrubber, clarifier, dense media separator, Derrick screen, trommel, separators, sumps, split deck, and rotary screen); purchased support equipment (none); and rental equipment (generator, front-end loader, bobcat). Support equipment refers to pieces of purchased equipment necessary for operation. In this case, all support equipment has been optionally rented.

The Bergmann USA Soil/Sediment Washing System used during the Demonstration Tests was a pilot-scale unit, with a maximum feed rate of about 5 tons/hr. The equipment cost of this system is estimated at $1,200,000. For the 15 tons/hr system, the equipment cost is approximately $2,410,000. Full-scale (more than 20 tons/hr) systems are also available. The cost for a 25 tons/hr system is approximately $3,367,000. For a 100 tons/hr system, the equipment cost is estimated to be $7,500,000. The annualized equipment cost is based on a 10-year life of the equipment and a 6% annual interest rate. The annualized equipment cost is based upon the writeoff of the total initial capital equipment cost and scrap value [2,3] (assumed to be 10% of the original equipment cost) using the following equation:

$$\text{Capital recovery} = (V - V_s)\ \frac{i(1+i)^n}{(1+i)^n - 1}$$

Where V is the cost of the original equipment,
V_s is the salvage value of the equipment,
n is the equipment life (10 years), and
i is the annual interest rate (6%) [2,3].

4.3.4 Startup and Fixed Costs

On-line training of the local hires (feed and maintenance operators) is conducted by the supervisor and the lead operator. Training is assumed to be conducted simultaneously for all shifts over a period of 13 8-hour days.

For each project for which the Bergmann USA Soil/Sediment Washing System is commissioned, a period of 3 days is required for waste-specific testing of the system prior to the commencement of treatment. This includes checking out each of the systems individually with respect to the particular waste to be treated. Two shifts of 5 workers are required for a total of 16 hours a day during the waste-specific equipment testing. Actual operating time during this waste-specific testing will be 14 hours a day. Costs of initial equipment tests are limited to labor charges (see "Labor Costs," Section 4.3.5).

Working capital is the amount of money currently invested in supplies and consumables. The working capital costs of supplies and consumables is based on maintaining a one-month inventory of these items. (See "Supplies Costs," Section 4.3.6, and "Consumables Costs," Section 4.3.7, for the specific amount of supplies and consumables required for the operation of the Bergmann USA Soil/Sediment Washing System. These quantities were used to determine the amount of supplies and consumables required to maintain a one-month inventory of these items.)

The annual costs of insurance and of taxes are usually approximately 1% and 2 to 4% of the total equipment capital costs, respectively. However, the cost of insurance of a hazardous waste process can be several times more. For the purposes of this estimate, annual insurance and taxes together are assumed to be 10% of the equipment capital costs [3]. These costs have been prorated for the length of the project.

The cost for the initiation of monitoring programs has not been included in this estimate. Depending on the site and the location of the system, however, local authorities may impose specific guidelines for monitoring programs. The stringency and frequency of monitoring required may have significant impact on the project costs.

An annual contingency cost of 10% of the equipment capital costs is allowed for any unforeseen or unpredictable cost conditions, such as strikes, storms, floods, and price variations [3,4]. Contingency is also prorated for the duration of the project.

4.3.5 Labor Costs

Labor costs are limited to salaries along with airfare and per diem for non-local personnel. For each shift, required personnel are estimated to be: 1 supervisor at $60/hr, 1 lead operator at $50/hr, 1 feed operator at $30/hr, 2 maintenance operators at $30/hr. Two shifts will be required with an allotment of one hour for overlap between shifts. Rates include overhead and administrative costs.

4.3.6 Supplies Costs

Based on data from previous operations, over a period that reflects operating conditions similar to those experienced during the Demonstration Tests, the costs for spare parts, and office/general supplies that are actually used to process each ton of waste using the 5 tons/hr system are estimated at $6. These costs drop to $4.75, $3.50, and $2.20 for operation of the 15, 25, and 100 tons/hr systems, respectively. Chemicals, also included in this cost category, consist of surfactant and flocculant for water treatment. During the Demonstration Tests, flocculant was used at a rate of less than 1 pound per ton of waste fed; surfactant was used at a rate of approximately 2 pounds per ton of waste fed.

4.3.7 Consumables Costs

Consumables required for the operation of the Bergmann USA Soil/Sediment Washing System are limited to diesel fuel, water, and electricity. For the 5 tons/hr system, fuel consumption for operation is limited to that used by the rented support equipment (i.e., the front-end loader and the bobcat). The system may, if desired be operated via an on-board generator. In this case, generator fuel (approximately 8 gallons per hour) will be required. The front-end loader utilizes approximately 2 gallons of diesel fuel per hour and the bobcat requires approximately 1 gallon per hour. The cost of diesel fuel varies with current market value but is assumed to be $1/gallon.

Although large amounts of water pass through the process, much of this water is recycled, thereby reducing potentially high costs for water supply. For the purposes of the cost calculations, a 2-inch meter was assumed. For a 2-inch meter, a base allowance of 30,000 cubic feet (cf) per quarter exists. Once this allowance is exceeded, additional charges are assessed. The following water rates, available for commercial use in Bay City, Michigan are used assuming a 2-inch meter:

- base charge per quarter $272
- meter-reading charge per quarter $36
- charge per cf beyond base allowance $0.014

The Bergmann USA Soil/Sediment Washing System utilized during the Demonstration Tests was a mobile facility that operated using a generator to supply electric power. However, long term operations greater than 4 months justify the use of electricity from the local power company. The 5 tons/hr unit requires approximately 150 kW (300 kW for the 15 tons/hr, 600 kW for the 25 tons/hr, and 1,800 kW for the 100 tons/hr systems.) The electricity rates from the local power company in Bay City, Michigan are as follows:

- base charge per month $5.96
- charge per kilowatt-hour $0.0826

4.3.8 Effluent Treatment and Disposal Costs

One effluent stream is anticipated from the Bergmann USA Soil/Sediment Washing System. This is the clarifier underflow generated by the system. The effluent is anticipated to be non-hazardous and suitable for disposal in the local sewer system, therefore, no treatment or disposal costs exist for the effluent stream. The fines and the humic fraction generated by the process are assumed to be residuals; see "Residuals and Waste Shipping, Handling, and Transport Costs," Section 4.3.9.

4.3.9 Residuals and Waste Shipping, Handling and Transport Costs

Waste disposal costs include storage, transportation, and treatment costs and are assumed to be the obligation of the responsible party (or site owner). It is assumed that the only residual or solid wastes generated from this process are the fines and the humic fraction. Since the Bergmann USA Soil/Sediment Washing System isolates and concentrates contaminants into a reduced volume of hazardous waste without actually treating the feed material, these residuals may require treatment such as incineration prior to their ultimate disposal. The cost for incineration and disposal may range from $200 up to $1,000 per 55-gallon drum. Landfill is the anticipated ultimate disposal method for these materials. Transportation costs must also be considered. Rates are generally in the vicinity of $3,000 for a full truck load and $1,500 for a half truck load.

4.3.10 Analytical Costs

Standard operating procedures for Bergmann USA include collection and analysis of 4-hour composite samples from three different streams (the fines, the humic fraction, and the washed coarse fraction) four times each day. This results in the collection and analysis of 12 samples per day. Each analysis costs approximately $100. Periodic spot checks may also be executed at Bergmann USA's discretion to verify that equipment is performing properly and that specified criteria are being met. Additionally, the client may elect, or may be required by local authorities, to initiate an independent sampling and analytical program at their own expense.

The analytical costs associated with environmental monitoring have not been included in this estimate due to the fact that monitoring programs are not typically initiated by Bergmann USA. Local authorities may, however, impose specific sampling and monitoring criteria whose analytical requirements could contribute significantly to the cost of the project.

4.3.11 Facility Modification, Repair and Replacement Costs

Maintenance labor and materials costs vary with the nature of the waste and the performance of the equipment. For estimating purposes, total maintenance costs (labor and materials) are assumed to be 10% of the equipment costs on an annual basis. The ratio of labor costs to materials costs is typically 40:60. Maintenance labor has previously been accounted for under "Labor Costs," Section 4.3.5; maintenance materials costs are estimated at 60% of the total annual maintenance costs and prorated for the time required for treatment. Costs for design adjustments, facility modifications, and equipment replacement are included here.

4.3.12 Site Restoration Costs

Site cleanup and restoration is limited to the removal of all excavation equipment from the site. Filling, grading or recompaction requirements of the soil will vary depending on the future use of the site and are assumed to be the obligation of the responsible party.

References

1. *Test Methods for Evaluating Solid Waste*, U.S. Environmental Protection Agency. Office of Solid Waste and Emergency Response. U.S. Government Printing Office: Washington, D.C., November 1986, SW-846, Third Edition, Volume IB.

2. Douglas, James M. *Conceptual Design of Chemical Processes*; McGraw-Hill, Inc.: New York, 1988.

3. Peters, Max S.; Timmerhaus, Klaus D. *Plant Design and Economics for Chemical Engineers*; Third Edition; McGraw-Hill, Inc.: New York, 1980.

4. Garrett, Donald E. *Chemical Engineering Economics*; Van Nostrand Reinhold: New York, 1989.

Appendix A

Process Description

A.1 Process Overview

The basic concept of soils and sediment washing may be envisioned by viewing the contaminated deposit as an ore body and the contaminants as the "valuable constituent." As such, the barge-mounted Bergmann USA plant incorporates a wide range of standard mineral processing and ore enrichment unit operations that can be brought on-line or taken off-line as required to remove these contaminants effectively. This flexibility thus allows for "customized" site- and/or contaminant-specific unit operations required for full-scale remediation at each site where it is employed.

The process flow diagram for the Bergmann USA Soil/Sediment Washing System used during the Demonstration Tests is shown in Figure A-1.

A.2 Process Description

Unprocessed soil or sediment is retrieved from a stockpile by a front-end loader. The loader empties its bucket into an 8-foot × 8-foot feed hopper. This hopper is designed to cope with the viscous character of the feed material and deliver a particle, nominally two inches in size, maximum. From the feeder module, material is transferred on a series of 24-inch wide conveyor belt to the head box of a rotary trommel screen. The first conveyor belt is equipped with a belt scale to monitor the amount of material fed to the system.

The trommel unit is an inclined, rotating cylinder that is three feet in diameter and twelve feet long. The unprocessed soil or sediment is fed into the high end of the trommel. The unit contains two distinct zones: the first is a washing/deagglomeration zone, and the second is a sizing zone. As feed material enters the trommel headbox, it is combined with the overflow water from a downstream cyclone separator (approximately 100 gpm). From the headbox, the slurry moves into the washing zone of the trommel where it is tumbled with the aid of lifter bars that run parallel to the long axis of the unit. Water sprays inside the trommel to further deagglomerate and slurry the dredged material. When the slurry reaches the second zone in the trommel, it is presented to a profile wire screen to effect a 6-mm cut. Material coarser than 6 mm is discharged out the end of the trommel and collected in a drum. Water and material less than 6 mm falls through the profile screen and is collected in a 450-gallon sump.

A 2-inch × 2-inch Linatex Model SC horizontal centrifugal slurry pump is connected to this sump. This pump is lined with Linatex natural rubber to ensure long life when handling abrasive slurries. The drive on this slurry pump (along with three other identical pumps on the plant) is a standard 7.5 HP, 1750 RPM, TEFC motor connected to a variable pitch V-Belt setup. The duty of this pump is to deliver a nominal 130 gpm of slurry containing approximately 15% solids by weight to the first cyclone.

In order to minimize water usage while simultaneously utilizing several stages of washing through the cyclone separators, the Bergmann USA plant was designed to operate in a countercurrent scenario. The soil moves in one direction through the plant, and the water moves in the opposite direction. In this manner, the washing potential of the process is maximized. Overflow from the third cyclone separator is used as dilution water to the second cyclone separator, and similarly, overflow from the second cyclone separator is introduced to the trommel feed for ultimate use in the first cyclone separator.

The cyclone separators used in the Bergmann USA plant are 9-inch diameter Linatex Separators. They include a tangential feed entry, a continuous length of overflow pipe that breaks to atmosphere several feet below the cyclone apex, and an underflow regulator. These features enable the units to provide a consistently dense underflow (coarse) product regardless of variations in the feed slurry solids content. This greatly reduces the bypass of unclassified material to the underflow. The density (or solids concentration) of the underflow slurry is regulated by the balancing of forces between a vacuum created by the long overflow pipe and the weight of solids that accumulate in the underflow regulator below the spigot. An air bleed is provided on the overflow pipe to allow on-line adjustment of the underflow solids concentration. Because of these distinctions from a standard cyclone, these units are referred to as *separators*.

The first stage separator is fed from the #1 pump via a 2-inch diameter slurry hose. Inlet pressure at the separator is 7 to 10 psi. The coarse fraction exiting the separator underflow is directed to a Linatex Dense Media Separator (DMS) Hydrosizer™. The DMS is a rectangular-shaped tank with approximate dimensions of 2 feet × 2 feet × 16 feet tall. Water is injected near the base of the DMS at 30 gpm, thus creating an upward current. As the solid particles exiting the Separator 1 meet this rising current, a teetered bed of soils (analogous to a quick sand) begins to form. Control of the density of this bed is maintained via a differential pressure cell (located on the side of the tank) that acts together with a pneumatic controller and underflow valve. As the density of the bed rises above a set point, the DMS underflow valve opens to purge some solids from the tank. Conversely, as the density of the sand bed drops, the underflow valve responds by closing down and restricting solids from exiting the tank. This bed of sand thus acts as an autogenous dense media that allows the operator to remove light organic particles (specific gravity < 1.6) from the sand fraction. Removal of these organics is important because this fraction of material generally acts as a primary host to contaminants.

The sand that exits the DMS is directed, by gravity, to an attrition scrubbing machine. This unit receives the sand fraction at a high solids concentration (normally 65 to 75% solids by weight) and, through a series of rotating impellers, acts to remove surficial contaminants on the sand grains. The particular unit in this demonstration plant consists of three chambers, each equipped with three impellers that rotate at a nominal tip speed of 800 rpm. Retention time within the machine is about 15 minutes at a feed rate of 5 tons/hr dry solids. In order to aid the scrubbing process, various reagents such as surfactants or pH modifiers may be added to the feed of the attrition cell. Discharge from the attrition cell is sent (by gravity) to Sump 2.

Sump 2 is a 450-gallon tank that receives material from the attrition cell (or directly from the DMS when the attrition cell is bypassed) as well as dilution water from the overflow of the third separator. From this sump, the slurry is pumped to the second stage separator for separation of fines. Underflow (sand fraction) from the second separator

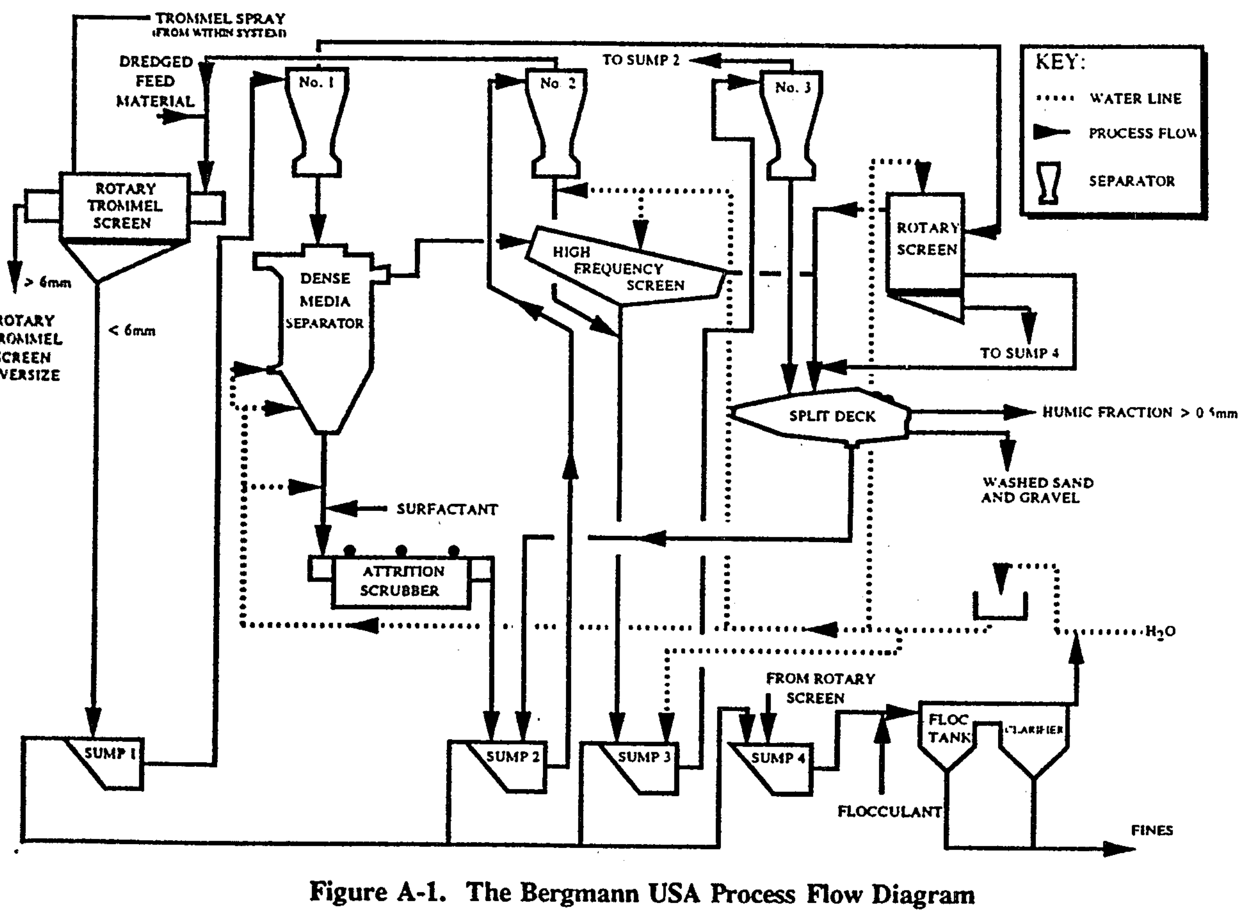


Figure A-1. The Bergmann USA Process Flow Diagram

is sent, by gravity, to Sump 3. This sump receives clarified process water from the inclined plate clarifier overflow. From here, the slurry is pumped (through a 2-inch × 2-inch slurry pump and 2-inch diameter hose) to the third stage separator for final hydraulic separation of fines. The underflow from the third separator falls by gravity onto a dewatering screen in order to produce a material which is suitable for discharge onto a 24-inch wide conveyor belt.

The dewatering screen used in this plant is a model VD-6 Linatex-Velco screen. It is 2-feet x 7-feet and inclined 5 degrees from the feed end up to the discharge end. The screen is powered by two counter-rotating vibratory motors to effect a nominal 6 mm stroke at 900 RPM. The screen deck is a profile wire system with 0.25 mm slots that yield an open area of approximately 13%. Along its length, the screen surface is divided by a polyurethane wall. On one side of this wall, sand from Separator 3 is dewatered. On the opposite side of the wall, the organic fraction recovered by the unit operations is dewatered and conveyed to a discharge chute.

As previously mentioned, organic matter is removed from the system by the DMS. However, organics are also removed to a lesser degree by the separators. In the separators, classification mechanism is ultimately tied into the settling velocity of the particles through the liquid medium. Therefore, low gravity organics tend to go to the separator overflow along with fine sand and clay fraction. The organics that appear in the overflow of Separator 1 are removed by passing the overflow slurry through a rotating wire mesh screen. The rotating screen, known as a Linatex Rotary Velmet screen, is equipped with 0.5 mm × 0.5 mm wire mesh cloth. It revolves at a speed of 1 RPM. The overflow from Separator 1 is directed to the inside of the revolving cylinder. Water and fine solids pass through the wire surface. The organics, which are typically fibrous in morphology, are trapped on the surface of the wire mesh. As the screen revolves, the organics are washed from the screen surface via a spray bar located on the outside of the cylinder. The organics and wash water fall into a chute that directs the stream to the Linatex-Velco dewatering screen. Prior to reporting to the dewatering screen, the overs (humic and coarse fraction) from the DMS are also screened on a 2-foot × 3-foot Derrick vibrating screen. This allows recapture of any fine sand which will inevitably report to the overflow of the DMS. Again, the Derrick screen overs are dropped directly onto the Linatex-Velco dewatering screen. Unders (fines) from both the Derrick screen and the Linatex-Velco screen fall by gravity to Sump 3 (or optionally Sump 2) for recombining with the sand fraction.

The fine fraction and water pass through the Rotary Velmet screen flow by gravity to Sump 4. From this sump, the slurry is pumped via a 2-inch × 2-inch pump into a Linatex Model 4C2-400 Clarifier. To aid in clarification, the effluent from the classification plant is dosed with polymer flocculants. (During the Demonstration Test Percol 720 from Allied Colloids was used as the flocculant.) Sludge containing approximately 15% solids is pumped out from the clarifier at timed intervals to a receiving tank. Overflow from the clarifier may be recycled back into the process.

Appendix B

Vendor's Claims

This appendix summarizes the claims made by the developer, Bergmann USA, regarding the Soil/Sediment Washing Technology, the technology under consideration. This appendix was generated and written solely by Bergmann USA, and the statements presented herein represent the vendor's point of view. Publication here does not represent the USEPA's approval or endorsement of the statements made in this section; the USEPA's point of view is discussed in the body of this report.

B.1 Introduction

The primary objective of the operation of a soils washing system is to process contaminated soil to remove metals, radioactivity, or organic contaminants from soil particles greater than 63 microns (230 mesh) to acceptable cleanup, or release levels. Soils/sediment washing is a waste minimization and volumetric reduction process in support of remediation activities at Superfund, RCRA, ACOE, DOD and DOE sites. The goal of this process is to separate clean coarse material from contaminated fines for further processing by others.

B.2 Proposed Technology/Approach

B.2.1 The Bergmann Soil/Sediment Washing Process

Soil and sediment washing is an aqueous/water-based, volume reduction process whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume using physical and chemical methods. The process concept involves transfer of the contaminants from the soil or sediment to the washwater and their subsequent removal from the water. Cleaned coarse sand and gravel portions of the treated soil/sediment may be redeposited on site or otherwise beneficially used as construction fill material, concrete and asphalt aggregate, or daily landfill cover. The small volume of contaminated residual concentrate is subsequently treated by other destructive, immobilization, or disposal technologies such as:

- incineration
- chemical extraction
- biodegradation
- vitrification
- low temperature thermal desorption
- dechlorination
- solidification/stabilization
- regulated disposal

The physical techniques that have been employed by the Bergmann technology have included crushing, screening, wet classification, attrition scrubbing, dense media separation, heavy media separation, elutriation, dissolved air flotation, gravity separation and mechanical dewatering. Associated chemical additives include detergents, surfactants, chelating agents, solvents, coagulants, flocculants and pH adjustment.

B.2.2 Applications

The Bergmann USA technology has been successfully applied for full-scale treatment and remediation of organic and inorganic contaminated material occurring not only at hazardous waste sites, but within bays, harbor and river areas. Bergmann USA provides clients with state-of-the-art pilot-scale (250 kg/day) or full-scale (10 to 50+ tons/hr) soils/sediments washing systems for utilization as the primary feedstock preparation system and volumetric reduction step prior to treatment, regulated destruction or disposal of the contaminated fines.

The process is an effective and economical remedial technology when the contaminated soil or sediment contains no more that 40% silt and clay material smaller than 63 micron (230 mesh). Solid organic material (leaves, twigs, roots, wood chips, etc.) should not exceed approximately 20% by volume.

Typical hazardous contaminant groups which have been effectively (90% +) removed from coarse soil and sediment fractions include:

- Petroleum/heavy fuel residuals
- Heavy metals
- PCPs (i.e, creosote)
- Cyanides/Sulfides
- Radioactive contaminants
- PCBs
- Pesticides

B.2.3 Effectiveness

Contaminant extraction efficiencies of 90 to 99% have been achieved by employing Bergmann commercial soil washing systems. Cleanup performance is in all cases site-specific, and dependent upon the particular physical and chemical properties of the contaminated soil or sediment. A laboratory treatability study is an essential first step. On occasion, on-site tests are conducted using mobile or transportable Bergmann 250 kg/day pilot plant equipment.

B.2.4 Waste Minimization

Soils and sediment washing can make an important contribution to waste minimization when used for <u>pretreatment</u> in conjunction with other destructive or immobilizing processes. Normally, this process results in the concentration of hazardous contaminants into a residual (<63-micron) product representing only 10 to 30% of the original volume. The washed (decontaminated) coarse fractions (>63 microns), representing 70 to 90% of the original volume, can either be redeposited on site or otherwise beneficially used.

B.2.5 Produces an Enriched, Homogeneous Feed for Downstream Processes

The residual contaminant concentrates produced from the soils/sediment washing operations provide a highly efficient feedstock for downstream or "trained" destructive, immobilization, or disposal technologies such as:

- incineration
- ion exchange
- biodegradation
- vitrification
- low temperature thermal desorption
- chemical dechlorination
- solidification/stabilization
- regulated disposal

The performance of such ultimate treatment technologies can be substantially enhanced by the use of a Bergmann washing system which produces a preprocessed feedstock, uniform size (<63 microns). "Difficult-to-process" oversized and debris fractions are thereby eliminated, and a homogeneous contaminant matrix blending highly concentrated "spikes" with portions of "non-detect" material is produced.

B.2.6 Cost Effectiveness

On-site soil washing is a highly cost effective remedial option. Typical comparisons are given below for a clean-up project involving 50,000 cubic yards of soil/sediment contaminated with PCBs. The following illustrative example assumes that residuals requiring further treatment or disposal are 15% of the original volume processed.

Destruction by Incineration Only (50,000 yd^3) $50,000,000	Soil Wash Pretreatment with incineration of residuals $12,250,000
Disposal in a RCRA designated landfill (50,000 yd^3) $12,500,000	Soil Wash Pretreatment with landfill disposal of residuals $6,625,000
Destruction by Dechlorination (50,000 yd^3) $11,500,000	Soil Wash Pretreatment w/dechlorination of fines $6,475,000
Solidification/stabilization with off-site landfill storage (50,000 yd^3) $8,000,000	Soil Wash Pretreatment with solidification/stabilization of residuals with off-site landfill storage $5,950,000

<u>Unit Costs Used for Comparisons:</u>	<u>Per yd^3</u>
Incineration - including residual removal and haulage costs	$1,000
RCRA Landfill - including excavation, haulage and tipping costs	$ 250
Chemical Dechlorination	$ 230
Solidification/stabilization with disposal at an off-site location	$ 160
Soil Washing Pretreatment - excluding excavation	$ 95

B.2.7 Community & User Acceptance

Soils washing is a safe, non-offensive, publicly accepted technology which is not viewed with the multitude of community concerns associated with incineration and large-scale hazardous landfill operations.

On-site treatment has become a highly desirable option owing to the much higher costs of transportation for off-site treatment, minimization of long term liabilities, negative community response to offensive large-scale trucking, and the benefit which can be realized from backfilling the washed (clean) material in the area from which it was excavated.

B.2.8 Commercial Scale Systems

Bergmann BV (Holland) is the world's leading company in the field of soils and sediment washing technology, having designed and fabricated eighteen full-scale, commercial installations ranging in size from 5 to 350 tons/hr. Bergmann USA has been established as the soils/sediment washing and volumetric reduction technology center for all North American projects. Bergmann USA has provided two 10 tons/hr transportable systems and a 250 kg/day mobile pilot plant for radioactive applications; additionally, Bergmann USA is fabricating a new 10 tons/hr soils washing plant for a lead battery Superfund site remedial project. Our staff includes internationally recognized specialists in the field.

B.2.9 Rapid Mobilization/Demobilization

Bergmann skid-mounted, transportable equipment modules (or trailer-mounted pilot-scale mobile units) can be readily placed on-site and easily moved to the next project location. Of the twenty full-scale Bergmann plants in operation today, ten exclusively process contaminated harbor, river, lake, canal, and bay sediments. A number of these plants are on floating barge platforms allowing for close proximity to dredge operations.

Bergmann transportable, full-scale, treatment systems consist of equipment modules which can be readily transported from site-to-site. Special attention is given to ease of mobilization and decommissioning following the completion of a project. Modules are pre-piped and pre-wired with quick interconnections. A Bergmann engineer and technician provide technical assistance with the erection, start-up and on-site training of operators. Mobilization and assembly of a 25 to 50 tons/hr Bergmann plant can be typically accomplished in 7 to 10 working days following completion of site preparation activities.

The complete erection and assembly of the modularized Bergmann 10 tons/hr plant aboard the U.S. Army Corps of Engineers' (USACE) 120' × 33' barge for the PCB sediment washing demonstration in the Saginaw River required four days. Total plant disassembly, decontamination and off-site demobilization required four days.

The Bergmann soil and sediment technology utilizes standardized "modules" which can be incorporated or deleted from a full-scale remedial operation based upon site-specific material and contaminant characteristics. Examples of specific modules which are interchangeable within the basic system configuration are:

1. Dual Step Grizzly Bar Screen - classification, separation and removal of +2" oversized debris material from raw feed;

2. Tramp Metal Separator - removal of ferrous tramp iron and steel from $+^3/_8$" feed material;

3. Rotary Trommel Screen - system utilized for initial break-up and deagglomeration of lumpy contaminated soil fractions. Primary feed is approximately 2" with screened coarse product fractions occurring at $+^3/_8$";

4. Oil & Grease Separation System - concentration and removal of light and heavy hydrocarbon oil products from wastewater system for separate concentration and disposal;

5. Attrition Scrubbing Module - a high energy unit process operation which contacts $-^3/_8$" contaminated material with chemical wash additives to effectively solubilize appropriate contaminants and to "deslime" or mobilize the highly contaminated fines (<74 micron [200 mesh]) material. The attrition cells function at a 75 - 80 % solids content;

6. Dense Media Separator Module - for separation and removal of vegetative and marine organic materials (leaves, twigs, roots, wood chips, plants, shells, etc.) based upon differential specific gravities;

7. Cyclone Separator Units - a high efficiency solids/liquid flash separation device utilized for the desliming (< 74 microns clay silt and colloidal material) from coarse (sand and gravel) soils fractions. Unit operates with no internal moving parts on the basis of differential specific gravities

of light and heavy media. Units deliver a coarse underflow of approximately 70 to 75% solids regardless of influent solids loading concentrations.

8. Reverse Slope Dewatering Module - a high frequency mineral screen assembly specifically designed for final rinsing, dewatering, desliming and removal of very fine material from mineral slurries. Each unit utilizes snap-in, modular screen deck panels and replaceable, bolt-in, side liner plates.

9. Washwater Clarifier Treatment Module - a compact water treatment system specifically designed for flocculation/sedimentation and gravity separation of fine (<74 micron) contaminated clay, silt and colloidal materials. System utilizes a quiescent settling zone for preliminary sludge densification prior to remove by a screw auger conveyor. Unit incorporates a pH adjustment system and polymer mix tank and chemical feed pump for coagulation operations.

10. Dissolved Air Flotation Module - for the precipitation, flocculation and removal of dissolved heavy metal hydroxide fractions from wastewater;

11. Sludge Densifier - gravity conditioner to bring residual solids content within sludge to a maximum of 30% to 35% for subsequent residual management technologies requiring a thickened slurry feed, such as: biodegradation; chemical extraction; or solidification/stabilization;

12. Continuous Belt Filter - module for continuous dewatering operation of mineral (< 63 micron) sludges and intermittent metal hydroxide Dissolved Air Flotation scum dewatering. Solids content of filter cakes will range from 60-70% solids.

Bench-scale treatability evaluations are critical in not only identifying applicable chemical additives for wash solutions, but also identified which critical unit process operation treatment module needs to be included in a full-scale remedial system.

B.2.10 Key Bench-Scale Treatability Modules

The bench-scale operation of key system unit operations provides for a reasonably accurate estimate as to how a pilot and/or full scale remedial system should behave. Key elements of the bench soils washing technology are particle size separation operations (high frequency screening), trommel washing and deagglomeration, attrition scrubbing, elutriation, sedimentation, flocculation, dissolved air flotation and fines dewatering.

B.2.11 Integration/Linkages to Other Technologies

As stated previously, the Bergmann soil/sediment technology <u>is not a stand alone</u> remedial operation. Where applicable, it is intended to be a waste minimization, volumetric reduction, feedstock preparation, pre-treatment step for a subsequent destructive, immobilization or disposal technology. Bergmann works very closely with the client and other selected technology vendors in providing them with an "enriched," homogenous feedstock material for subsequent innovative treatment or immobilization evaluations.

B.2.12 Beneficial Recycle/Reuse of Process Products

As has been stated previously, the washed, "clean," >63-micron coarse sediment fractions (gravel & sand), typically can be reused as fill material directly to the original excavation, or beneficially reused as a clean, graded construction foundation material, or Hanford on-site concrete/asphalt sand aggregates.

B.2.13 Technology Familiarization, Environmental Assessment and Track Record

Bergmann has designed, constructed, and delivered 20 full-scale soil and sediment washing plants: 18 throughout Europe, ranging in size from 10 to 350 tons/hour; and two additional plants were delivered within North America. In October 1991 a 10 tons/hr plant was shipped to the Toronto Harbour Commission and a 10 tons/hr sediment washing plant was installed for the USACE at Saginaw Bay, Michigan.

B.2.14 Process Flow Schematic, Emission Controls and Sampling Points

The control, collection and treatment of fugitive dusts and emissions has been readily accomplished in the 10 tons/hr Bergmann USA system operated at the Toronto Harbour Soils Recycling Project through the engineered application of covers and shroud assemblies incorporated into the conveyor, hopper bin, and tank designs along with a 5,000 scfm large volume air handling systems into Calgon Vapor Pack 10 Adsorbers containing 12,000 pounds of activated carbon.

The primary concerns with the handling of contaminated soils are two-fold: 1) worker exposure, and 2) downwind, off-site community exposure. Radionuclide and chemical constituents which exhibit moderate to high volatility are of principal concern. During excavation/removal of the contaminated matrix, the majority of the anticipated release of these low vapor pressure materials will occur prior to preliminary screening and soil/sediment washing and processing.

The USEPA has issued a report evaluating numerous techniques for the control and treatment of fugitive dusts and emissions in the handling and treatment of contaminated soils from Superfund sites. Preliminary wetting or "fogging" of dry contaminated soils during excavation will effectively suppress the majority of volatile organic chemicals and virtually any associated "dusting" and blowing of inorganic fine fractions. Obviously, during dredging operations, the contaminated sediments are totally saturated, thereby negating any possibility of dusting occurring.

Semi-volatile and non-volatile organic chemicals (i.e., oils, greases, diesel fuels) pose little to no environmental or health threat to the site workers or the off-site community at large. Due to their inherently low vapor pressure, little to no volatilization is generally detected. All volatilization rates are temperature dependent. The colder the ambient operational temperature, the less volatilization will occur.

Control methods that have been and are being applied, when required, in the soils and sediment washing system, involve the covering or shrouding of piles, bins, hoppers, conveyors, and tanks. These subcomponent systems are then negatively vented through the application of explosion-proof induced draft air fans. Any volatile emissions or nuisance vapors are totally collected and drawn through granular, vapor phase, activated carbon packs or canisters. Once the carbon has been exhausted or experiences "breakthrough," it can be removed from the system for either on-site or off-site regeneration and then placed back into service.

For extremely toxic or dusty materials (i.e., dioxin, radionuclides) high efficiency particulate air (HEPA) systems have been very successfully applied in full scale remedial operations.

A final alternative to fugitive volatile emission and dust control is the erection of a temporary structure over either the excavation site, treatment system, or both. These temporary buildings can be either of sheet metal, (i.e., Bulter Buildings), or a supported fabric, internal frame design structure, (i.e., Rubb or Sprung Structures). The building can then be negatively vented through a vapor collection/treatment system.

Each site must be assessed for fugitive vapor and dust emissions through a long-term ambient air monitoring program. This is accomplished through the positioning of long-term (24-hour) air sampling stations around the site and at the face of the contaminated soil/sediment excavation. Once adequate data is obtained to identify primary volatile chemical constituents and their concentrations, properly sized vapor/dust emission collection and control systems can be readily incorporated into the site-specific remedial technology design and operating procedures.

Appendix C

Site Demonstration Results

This section summarizes the results of the SITE demonstration of the Bergmann USA Soil/Sediment Washing Technology as they pertain to the evaluation of the developer's claims. These results are further discussed in Section 3 of this report. A more detailed account of the demonstration is found in the companion Technology Evaluation Report.

Bergmann USA claims that their technology, the Soil/Sediment Washing system, can separate 90% of the <45-micron particle size fraction from the bulk feed material. These tests were conducted to evaluate this claim. Additionally, the tests were devised to determine the distribution of organic contaminants (PCBs) and of inorganic contaminants (metals detected using USEPA SW-846 Method 6010 and mercury) in all input and output streams. Therefore, the results of these tests focus primarily on the particle size distribution, the PCB distribution, and the metals distribution in the output streams.

The demonstration activities consisted of two separate tests using the same feed soil throughout. The tests were identical except Test 2 investigated the effect of using surfactant while otherwise operating in the same fashion. Sampling of all process input and output streams was carried out in accordance with the Demonstration Plan [1]. Some minor modifications to the sampling plan were implemented in the field during the tests. These modifications are detailed in Section 5 of the Technology Evaluation Report.

The tables presented in this section provide a summary of the Demonstration Test data. Daily averages are presented for each stream. For all streams except S2, information presented for each day is an average of at least eight data points (1 sample per hour, 8 hours per day.) The data presented for S2 is an average of at least two data points since S2 was only sampled twice per day (one 4-hour composite in the morning and one 4-hour composite sample in the afternoon). In order to provide the most representative information, the averages and 95% confidence intervals presented for Test 1 have been calculated using all available data (at least forty data points for all streams except S2 where at least ten data points were utilized), and thus may not directly correspond to the averages of the four data points presented for Days 1 through 4 in the tables. All available data points for Days 1 through 5 were used for the calculation of the overall averages presented in the tables.

C.1 Solids Balance

The solids balance is presented in Table C-1. The total closure for the solids balance in Test 1 was 106%. The range was 101 to 115%. The value for Test 2 was 103%. The objective for total solids balance was 85 to 115%.

C.2 Particle Size Separation

Particle size separation was determined for all input and output streams. Specifically, information was collected to delineate the amount of material <45 microns in size for each stream. Table C-2 presents a summary of the percent of each stream that was <45 microns. (See Figure 1 for the locations of each of the streams and their appropriate sampling locations.)

The Test 1 input feed soil was comprised of approximately 21.4% <45-micron particles with a 95% confidence interval of 19.8 to 23.1%. For Test 2, the input feed soil was approximately 29.0% <45-micron particles. Particles in this <45-micron range were detected in the following output streams: the rotary trommel screen oversize (S2), the humic fraction (S5), the washed coarse fraction (S6), and the clarifier underflow or fines (S7).

During both tests, the majority of the particles in the <45-micron range were in the fines, S7, as expected. During Test 1, an average of approximately 94.4% (confidence interval of 93.1 to 95.6%) of this stream was <45 microns. During Test 2, fines were also approximately 94.4% <45

Table C-1. Solids Dry Mass Balance Data

	Mass In (lbs)	Mass Out (lbs)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	48,600	4,730	252	41,000	3,340	49,300	101
Day 2*	44,600	4,360	272	37,100	3,170	44,900	101
Day 3*	47,400	5,490	245	42,500	2,360	50,600	107
Day 4*	55,100	13,600	297	43,700	5,640	63,300	115
Average†	48,900	7,050	267	41,100	3,630	52,000	106
Test 2* (Day 5)	45,500	8,810	305	34,000	3,630	46,700	103
Overall Average‡ (Days 1-5)	48,200	7,400	274	39,700	3,630	51,000	106

* Value calculated from data collected throughout the day.
† Calculated using all available data point for Days 1 through 4.
‡ Calculated using all available data point for Days 1 through 5.

microns.

Table C-2 shows that particles <45 microns in size (fines) were also found in the rotary trommel screen oversize, S2, during both tests (an average of approximately 34.5% during Test 1 and approximately 41.9% during Test 2). This occurrence was not anticipated; the presence of particles <45 microns in this stream is undesired. Better separation of the fines from the trommel oversize may be achieved by the addition of a log washer or similar deagglomeration unit operation.

Table C-2. Particle Size Analysis Summary (% <45 microns)**

	Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	24.6	27.9	10.3	4.69	94.3
Day 2*	21.8	34.3	7.83	2.19	95.1
Day 3*	17.4	36.0	5.93	3.26	94.1
Day 4*	22.0	39.8	5.39	3.11	94.1
Average†	21.4	34.5	7.35	3.31	94.4
Lower 95% Confidence Interval†	19.8	30.0	5.92	2.61	93.1
Upper 95% Confidence Interval†	23.1	38.9	8.79	4.02	95.6
Test 2 (Day 5)*	29.0	41.9	9.72	5.04	94.4
Overall Average (Days 1-5)‡	22.9	36.0	7.83	5.04	94.4

* Average value calculated from data collected throughout the day.
** For a discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

The humic fraction, S5, contained only small amounts of particles <45 microns. Results from Test 1 show that an average of approximately 7.35% (95% confidence interval of 5.92 to 8.79%) of this stream was <45 microns. For Test 2, approximately 9.72% of the humic fraction was finer than 45 microns.

The washed coarse fraction, S6, was anticipated to have a very low percentage of particles <45 microns. This was indeed the case as seen in Table C-1. Test results show the percentage of particles <45 microns in the washed coarse fractions to be approximately 3.31% (95% confidence interval of 2.61 to 4.02%) and 5.04% for Test 1 and Test 2, respectively.

C.3 Distribution of PCBs

All input and output streams were evaluated for the presence of PCBs during the Demonstration Test. PCBs were detected in the rotary trommel screen oversize (S2), the humic fraction (S5), the washed coarse fraction (S6), and the clarifier underflow or fines (S7).

As seen in Table C-3a, PCBs were present in the feed, S1, at levels of approximately 1.30 mg/kg (average) for Test 1, and approximately 1.57 mg/kg for Test 2. After processing, PCBs were expected to be concentrated in the fines and in the humic fraction. Test results indicate that the concentration of PCBs in the humic fraction was higher than that in the fines. This was expected due to the preferential partitioning of PCBs to organic material within S5, the humic fraction. The humic fraction contained an average of approximately 10.4 mg/kg while the fines contained an average of approximately 4.61 mg/kg for Test 1. For Test 2, the humic fraction contained approximately 13.4 mg/kg and the fines 3.68 mg/kg.

Table C-3b presents the data regarding mass balances for PCBs for Tests 1 and 2. An average of 60.4% closure was achieved for the Test 1 mass balance. The results from Test 2 provide 51.7% closure on the mass balance. The goal for closure of the PCB mass balance (50 to 150%) was met for both Test 1 and Test 2.

C.4 Distribution of Metals

All input and output streams were evaluated for the presence of metals during the Demonstration Test. The samples were analyzed for all the metals specified by SW-846 Method 6010 and mercury. Metals were detected in the rotary trommel screen oversize (S2), the humic fraction (S5), the washed coarse fraction (S6), and the clarifier underflow or fines (S7). Demonstration Testing of the Bergmann USA Soil/Sediment Washing System identified eleven metals that were present in high enough concentrations to allow a suitable evaluation of the technology. Three metals that are regulated under the Resource Conservation and Recovery Act (RCRA) were detected too infrequently to be used to evaluate the technology. These metals were cadmium, chromium, and mercury. One RCRA regulated metal (arsenic) was analyzed for, but not detected.

Tables C-4a through C-14a present the average metals concentrations for eleven metals which were present in high enough concentrations to allow a suitable evaluation of the technology. In the discussion in Section 3, copper is considered to be a typical metal. Copper is therefore used to show contaminant fate of inorganic compounds. Aluminum was the only inorganic that behaved quite differently as referred to in Section 3. Alumina is a component of clay and therefore the behavior of aluminum with respect to the soil/sediment washibg of a clay material could not be evaluated.

Tables C-4b through C-14b present the metals mass balances for these same eleven metals. (Note that the tables are presented in different units; some are reported in g and some are reported in kg). The results of the mass balance for metals depended on the particular element of interest. The mass balance tables indicate that the mass balances for each metal identified (with the exception of lead) improved each day with the progression of testing.

Table C-3a. PCB Concentration Data (mg/kg)

	Input Feed S1	Rotary Trommel Screen Oversize S2	Humic Fraction S5	Washed Coarse Fraction S6	Clarifier Underflow (Fines) S7
Test 1					
Day 1*	1.14	0.953	8.33	0.253	5.57
Day 2*	1.23	2.13	7.58	0.213	4.93
Day 3*	1.13	2.20	14.7	0.147	3.91
Day 4*	1.71	1.17	11.2	0.164	4.03
Average†	1.30	1.61	10.4	0.194	4.61
Lower 95% Confidence Limit†	1.27	1.11	10.0	0.188	4.53
Upper 95% Confidence Limit†	1.33	2.12	10.8	0.200	4.70
Test 2 (Day 5)*	1.57	1.35	13.4	0.189	3.68
Overall Average‡ (Days 1-5)	1.35	1.56	11.0	0.193	4.42

* Average value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-3b. PCB Mass Balance Data

	Mass In (g)	Mass Out (g)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	25.2	2.04	0.953	4.71	8.42	16.1	63.9
Day 2*	23.3	4.21	0.891	3.59	6.73	15.4	66.1
Day 3*	23.9	5.46	1.59	2.85	4.17	14.1	58.8
Day 4*	42.9	7.28	1.49	3.24	10.5	22.5	52.6
Average†	28.8	4.75	1.23	3.60	7.46	17.0	59.1
Test 2 (Day 5)*	32.4	5.63	1.84	2.91	6.36	16.7	51.7
Overall Average‡ (Days 1-5)	29.6	4.92	1.35	3.46	7.24	17.0	57.4

* Value calculated from data collected throughout the day.
† Calculated from all available data points for Days 1 through 4.
‡ Calculated from all available data points for Days 1 through 5.

Table C-4a. Aluminum Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	5,610	7,990	1,910	748	18,800
Day 2*	4,750	5,450	1,520	792	26,300
Day 3*	3,930	6,520	1,650	774	17,100
Day 4*	4,540	7,160	2,060	800	17,600
Average†	4,710	6,780	1,780	778	19,900
Lower 95% Confidence Limit†	4,300	5,890	1,630	760	16,100
Upper 95% Confidence Limit†	5,120	7,670	1,930	797	24,000
Test 2 (Day 5)*	4,960	8,250	2,220	957	20,600
Overall Average‡ (Days 1-5)	4,760	7,070	1,870	814	20,100

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-4b. Aluminum Mass Balance Data

	Mass In (kg)	Mass Out (kg)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	123	17.3	0.221	13.9	28.6	60.1	48.7
Day 2*	95.9	10.8	0.188	13.3	41.2	65.5	68.4
Day 3*	84.1	16.2	0.183	14.9	18.5	49.8	59.2
Day 4*	116	44.2	0.276	15.9	45.0	105	90.9
Average†	105	22.1	0.217	14.5	33.3	70.2	67.0
Test 2* (Day 5)	103	32.1	0.305	14.7	32.0	79.1	76.4
Overall Avg‡ (Days 1-5)	105	24.1	0.235	14.6	33.1	72.0	68.8

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-5a. Barium Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	39.1	64.9	127	5.51	130
Day 2*	35.5	45.7	62.2	6.15	177
Day 3*	32.0	51.7	70.9	6.21	135
Day 4*	42.6	58.3	85.0	7.54	135
Average†	37.3	55.2	86.3	6.35	140
Lower 95% Confidence Limit†	33.2	48.0	65.2	5.85	120
Upper 95% Confidence Limit†	41.4	62.3	107	6.85	170
Test 2 (Day 5)*	40.9	66.6	90.2	8.91	152
Overall Average‡ (Days 1-5)	38.0	57.4	87.1	6.86	146

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-5b. Barium Mass Balance Data

	Mass In (g)	Mass Out (g)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	863	141	12.9	103	197	453	52.6
Day 2*	719	90.4	7.74	104	276	478	66.5
Day 3*	686	129	7.98	120	145	401	58.6
Day 4*	1,120	360	11.4	149	347	868	77.8
Average†	846	180	10.0	119	242	550	65.1
Test 2* (Day 5)	850	263	12.3	137	264	676	76.4
Overall Avg‡ (Days 1-5)	847	197	10.5	123	241	570	67.3

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-6a. Calcium Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	29,500	44,900	23,500	12,200	73,100
Day 2*	26,100	28,300	18,800	14,300	94,200
Day 3*	24,300	30,800	19,800	14,700	72,000
Day 4*	27,600	34,400	23,100	14,700	67,600
Average†	26,900	34,600	21,300	13,900	76,700
Lower 95% Confidence Limit†	25,200	28,100	19,700	13,200	63,700
Upper 95% Confidence Limit†	28,500	41,100	22,900	14,700	90,300
Test 2 (Day 5)*	27,700	35,400	23,500	16,300	70,400
Overall Average‡ (Days 1-5)	27,000	34,700	21,700	14,400	75,500

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-6b. Calcium Mass Balance Data

	Mass In (kg)	Mass Out (kg)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	650	97.9	2.72	227	111	438	67.4
Day 2*	528	55.8	2.40	241	146	445	84.3
Day 3*	525	76.5	2.18	282	77.4	438	83.5
Day 4*	695	212	3.05	291	173	679	97.7
Average†	600	111	2.60	260	127	500	83.4
Test 2* (Day 5)	573	138	3.22	252	123	516	87.7
Overall Avg‡ (Days 1-5)	594	116	2.73	259	123	501	84.3

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-7a. Copper Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	24.1	34.6	65.5	6.04	72.2
Day 2*	24.0	28.0	47.7	6.47	85.3
Day 3*	18.1	27.1	53.9	9.04	63.3
Day 4*	23.6	26.9	67.9	9.70	60.8
Average†	22.5	29.2	58.8	7.81	70.4
Lower 95% Confidence Limit†	19.9	25.3	51.3	7.10	60.6
Upper 95% Confidence Limit†	25.1	33.0	66.2	8.52	80.6
Test 2 (Day 5)*	22.2	34.6	66.7	9.49	70.5
Overall Average‡ (Days 1-5)	22.4	30.3	60.3	8.15	70.4

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluatio Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-7b. Copper Mass Balance Data

	Mass In (g)	Mass Out (g)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	530	75.4	7.08	112	111	305	57.6
Day 2*	487	55.4	5.94	109	128	298	61.2
Day 3*	387	67.5	6.04	174	67.2	315	81.3
Day 4*	603	166	9.04	192	157	524	86.9
Average†	502	91.1	7.02	147	116	361	71.8
Test 2* (Day 5)	462	139	9.21	146	111	405	87.8
Overall Avg‡ (Days 1-5)	494	101	7.46	147	115	370	74.8

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-8a. Iron Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	8,910	12,900	17,700	2,190	25,000
Day 2*	7,720	8,680	12,300	2,380	33,700
Day 3*	6,770	9,960	13,000	2,300	25,700
Day 4*	7,600	11,100	14,600	2,350	25,500
Average†	7,750	10,700	14,400	2,310	27,500
Lower 95% Confidence Limit†	7,170	9,110	13,000	2,240	22,800
Upper 95% Confidence Limit†	8,320	12,200	15,800	2,370	32,400
Test 2 (Day 5)*	8,150	12,500	15,000	2,930	27,800
Overall Average‡ (Days 1-5)	7,830	11,000	14,500	2,430	27,600

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-8b. Iron Mass Balance Data

	Mass In (kg)	Mass Out (kg)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	196	28.0	2.06	40.8	37.7	109	55.3
Day 2*	156	17.2	1.51	40.2	52.5	111	71.4
Day 3*	145	24.8	1.45	44.2	27.7	98.2	67.8
Day 4*	193	68.6	1.89	46.6	65.3	182	94.5
Average†	173	34.6	1.73	43.0	45.8	125	72.5
Test 2* (Day 5)	169	49.1	2.07	45.1	43.4	140	82.6
Overall Avg‡ (Days 1-5)	172	37.5	1.80	43.4	45.3	128	74.3

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-9a. Lead Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	14.4	25.2	188	12.2	41.0
Day 2*	17.1	18.0	47.1	12.6	67.9
Day 3*	14.5	21.7	48.3	12.1	59.6
Day 4*	14.9	18.0	43.1	11.8	61.0
Average†	15.2	20.7	81.7	12.2	57.4
Lower 95% Confidence Limit†	12.9	17.1	12.2	12.0	47.3
Upper 95% Confidence Limit†	17.5	24.3	151	12.4	68.4
Test 2 (Day 5)*	15.5	24.7	61.8	12.7	62.9
Overall Average‡ (Days 1-5)	15.3	21.5	77.7	12.3	58.5

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-9b. Lead Mass Balance Data

	Mass In (g)	Mass Out (g)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	317	54.7	14.6	227	61.7	358	113
Day 2*	332	35.5	5.72	212	105	358	108
Day 3*	309	54.2	5.43	234	63.7	357	116
Day 4*	381	111	5.72	234	155	506	133
Average†	335	63.7	7.87	227	96.5	395	118
Test 2* (Day 5)	319	106	8.36	196	99.5	410	129
Overall Avg‡ (Days 1-5)	331	72.2	7.97	221	97.1	398	120

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-10a. Magnesium Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	8,710	12,400	2,950	3,570	20,900
Day 2*	7,330	7,900	2,760	3,930	27,600
Day 3*	6,430	8,470	2,550	4,220	20,800
Day 4*	7,790	9,730	3,490	4,160	20,000
Average†	7,560	9,630	2,940	3,970	22,300
Lower 95% Confidence Limit†	6,960	7,840	2,700	3,760	18,400
Upper 95% Confidence Limit†	8,160	11,400	3,180	4,180	26,400
Test 2 (Day 5)*	7,320	10,100	3,570	4,870	21,200
Overall Average‡ (Days 1-5)	7,520	9,740	3,060	4,150	22,100

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-10b. Magnesium Mass Balance Data

	Mass In (kg)	Mass Out (kg)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	192	27.1	0.339	66.4	31.6	125	65.5
Day 2*	148	15.6	0.354	66.3	43.0	125	84.5
Day 3*	137	21.1	0.291	81.4	22.4	125	91.0
Day 4*	193	60.1	0.468	82.5	51.3	194	101
Average†	168	31.0	0.363	74.2	37.1	142	85.5
Test 2* (Day 5)	150	39.5	0.491	75.1	36.9	152	100
Overall Avg‡ (Days 1-5)	164	32.7	0.389	74.3	37.0	144	87.8

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-11a. Manganese Concentration Distribution (mg/kg)**

	Input Feed S1	Rotary Trommel Screen Oversize S2	Humic Fraction S5	Washed Coarse Fraction S6	Clarifier Underflow (Fines) S7
Test 1					
Day 1*	218	357	472	51.6	646
Day 2*	195	233	370	57.8	885
Day 3*	183	274	391	62.3	700
Day 4*	206	309	470	64.8	698
Average†	200	293	426	59.1	732
Lower 95% Confidence Limit†	187	249	389	56.4	610
Upper 95% Confidence Limit†	214	338	462	61.9	862
Test 2 (Day 5)*	228	345	501	80.7	752
Overall Average‡ (Days 1-5)	206	304	441	63.4	736

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using available data points for Days 1 through 4.
‡ Calculated using available data points for Days 1 through 5.

Table C-11b. Manganese Mass Balance Data

	Mass In (g)	Mass Out (g)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	4,820	776	50.0	961	977	2,760	57.4
Day 2*	3,930	461	45.1	974	1,380	2,860	72.7
Day 3*	3,920	681	43.4	1,200	755	2,680	68.3
Day 4*	5,220	1,910	62.4	1,290	1,790	5,050	96.7
Average†	4,470	957	50.2	1,110	1,230	33,40	73.8
Test 2* (Day 5)	4,720	1,350	68.7	1,240	1,310	3,970	84.1
Overall Avg‡ (Days 1-5)	4,520	1,040	53.9	1,130	1,230	3,450	76.3

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-12a. Potassium Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	980	1,220	872	244	3,590
Day 2*	802	842	669	251	4,890
Day 3*	547	1,090	683	242	2,880
Day 4*	662	1,060	722	236	2,870
Average†	748	1,050	737	243	3,560
Lower 95% Confidence Limit†	664	925	675	240	2,880
Upper 95% Confidence Limit†	831	1,180	799	247	4,280
Test 2 (Day 5)*	738	1,340	804	241	3,640
Overall Average‡ (Days 1-5)	746	1,110	750	243	3,570

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 4.

Table C-12b. Potassium Mass Balance Data

	Mass In (kg)	Mass Out (kg)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	21.6	2.64	0.0978	4.55	5.56	12.8	59.5
Day 2*	16.2	1.67	0.0786	4.23	7.50	13.5	83.0
Day 3*	11.6	2.71	0.0723	4.67	3.09	10.5	90.6
Day 4*	17.0	6.55	0.0970	4.69	7.35	18.7	110
Average†	16.6	3.39	0.0864	4.54	5.88	13.9	85.8
Test 2* (Day 5)	15.5	5.31	0.110	3.72	6.23	15.4	99.2
Overall Avg‡ (Days 1-5)	16.4	3.78	0.0911	4.37	5.95	14.2	86.6

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-13a. Vanadium Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	17.1	20.5	26.4	6.12	46.4
Day 2*	14.3	13.9	20.8	6.28	62.4
Day 3*	9.78	16.1	23.0	6.07	43.9
Day 4*	11.4	18.2	24.2	5.93	43.4
Average†	13.2	17.2	23.6	6.10	49.0
Lower 95% Confidence Limit†	11.8	14.6	21.6	6.01	40.7
Upper 95% Confidence Limit†	14.5	19.8	25.7	6.19	57.9
Test 2 (Day 5)*	12.8	20.1	21.9	6.61	49.9
Overall Average‡ (Days 1-5)	13.1	17.8	23.3	6.20	49.2

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Reoprt.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-13b. Vanadium Mass Balance Data

	Mass In (g)	Mass Out (g)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	378	44.6	3.05	114	70.7	232	61.4
Day 2*	290	27.4	2.53	106	96.5	232	80.0
Day 3*	210	40.1	2.52	117	47.2	207	98.6
Day 4*	291	112	3.18	118	111	344	118
Average†	292	56.0	2.82	114	81.4	254	89.5
Test 2* (Day 5)	265	78.5	3.01	102	86.7	270	102
Overall Avg‡ (Days 1-5)	287	60.5	2.86	111	82.4	257	89.5

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-14a. Zinc Concentration Distribution (mg/kg)**

	Input Feed	Rotary Trommel Screen Oversize	Humic Fraction	Washed Coarse Fraction	Clarifier Underflow (Fines)
	S1	S2	S5	S6	S7
Test 1					
Day 1*	73.9	124	192	10.1	206
Day 2*	77.8	94.3	155	11.9	316
Day 3*	72.5	122	192	13.8	336
Day 4*	86.9	132	229	15.7	342
Average†	77.8	118	192	12.9	300
Lower 95% Confidence Limit†	70.1	104	170	12.0	255
Upper 95% Confidence Limit†	85.4	132	214	13.7	349
Test 2 (Day 5)*	93.0	167	229	21.0	376
Overall Average‡ (Days 1-5)	80.8	128	199	14.5	315

* Average value calculated from data collected throughout the day.
** For discussion of these data, see Section 8 of the Technology Evaluation Report.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Table C-14b. Zinc Mass Balance Data

	Mass In (g)	Mass Out (g)					Mass Out / Mass In
	S1	S2	S5	S6	S7	Total	Mass Balance (%)
Test 1							
Day 1*	1,650	267	21.1	188	312	788	47.8
Day 2*	1,570	187	19.0	201	493	899	57.3
Day 3*	1,560	303	21.3	266	361	951	61.2
Day 4*	2,210	814	30.1	311	880	2,040	91.9
Average†	1,750	393	22.9	242	512	1,170	64.6
Test 2* (Day 5)	1,910	691	31.1	323	661	1,710	89.2
Overall Avg‡ (Days 1-5)	1,780	452	24.5	258	541	1,280	71.9

* Value calculated from data collected throughout the day.
† Calculated using all available data points for Days 1 through 4.
‡ Calculated using all available data points for Days 1 through 5.

Appendix D

Case Studies

D.1 Assessment and Remediation of Contaminated Sediments Program Testing

Before the initiation of the SITE demonstration of Bergmann USA's Soil/Sediment Washing Technology at the Saginaw Bay Confined Disposal Facility (CDF), the U.S. Army Corps of Engineers (USACE) monitored a similar demonstration under the USEPA Great Lakes National Program Office's Assessment and Remediation of Contaminated Sediments (ARCS) Program [2]. The ARCS pilot-scale demonstration was performed on material dredged from the same approximate area of the Saginaw River as sediment used for the SITE demonstration using the same 5 tons/hr unit (equipped with a different clarifier). Sediments were mechanically dredged and placed on the CDF to dewater in October 1991. Plans called for the processing of approximately 290 cubic yards of material within a 2-week period. High winds and low temperatures forced suspension of the demonstration after only two days. Processing was resumed in May 1992 and completed immediately before the initiation of the SITE operation.

Monitoring planned for the ARCS demonstration was designed to look at the performance of various components of the Bergmann USA process rather than just the input and output streams. In order to accomplish this, samples were taken less frequently, and analyses were generally performed on composites of four-hour samples. Sampling conducted in the fall of 1991 may reflect some of the problems encountered during startup. These problems were largely related to a clay content in the feed material that was higher than expected, the inability to regulate feed rates, and a clarifier which was too small to adequately handle the volume of slurry containing fines. The feed unit was modified prior to spring operations to provide a more uniform feed rate and to partially break up large chunks of clay. The clarifier used in the fall was also replaced with a larger unit prior to spring operations.

At the time this document was prepared, no data were available from the spring ARCS demonstration. Examination of the grain size distributions at various points in the process during the 2-day fall run indicated that the unit being used has the potential to successfully separate sand from the finer and less dense materials. The cyclone separators appeared to be separating the fine and coarse material at a nominal grain size of about 38 microns. Based on laboratory work, separation at about 75 microns would result in a cleaner sand fraction. Separation at this smaller grain size is a artifact of processing parameters including cyclone separator diameter. The size of the pilot plant effectively limited the diameter of cyclone separator which could be used and ultimately affected the amount of PCBs associated with the sand fraction. A full-scale unit would likely be capable of improved results. The limited fall data indicate that the PCBs in the feed sediments averaged about 1.6 ppm and concentrations in the processed sand product were reduced to an average of 0.21 ppm.

D.2 Toronto Harbour Commissioners SITE Demonstration Testing

During the first half of 1992, Bergmann USA participated in another SITE Demonstration in which their Soil/Sediment Washing Technology was part of an overall treatment scheme involving several technologies working in conjunction for final cleanup of contaminated material from the Toronto Harbour, Toronto, Ontario, Canada [3,4]. In coordination with the Toronto Harbour Commissioners, Bergmann USA installed a 5 to 10 tons/hr pilot-scale Soil/Sediment Washing Unit for the demonstration of volumetric remedial operations coupled with innovative metals extraction and biodegradation technologies for the treatment of the $<$63-micron fines fraction.

A modular plant was transported and erected in-place on the site. The system was completely shrouded by a Rupp Fabric Building, and a tube heat exchanger was installed to raise the temperature of process operation wash water to approximately 80 to 90°F. Treatment commenced in January 1992 and continued for an initial 18-week period during which the SITE demonstration was performed. The sampling associated with this SITE project took place in April and May of 1992 when the pilot-scale unit was processing soil from a site that had been used for metals finishing and refinery and petroleum storage.

The Toronto Harbour Demonstration Tests found that the Bergmann USA Soil/Sediment Washing System produces two product streams with contaminant levels significantly reduced in comparison to the feed soil. In addition, the contaminants were found to be concentrated primarily in the contaminated slurry which is then routed for further processing. Table D-1 presents the average values of selected parameters measured during the demonstration for the feed and product streams.

To date, this Bergmann USA Soil/Sediment Washing plant has processed approximately 3,000 tons of heavy metal, polyaromatic hydrocarbon (PAH), polynuclear aromatic (PNA), and petroleum hydrocarbon contaminated materials. Additionally, Bergmann USA will process approximately 500 tons of contaminated dredge spoil from the Toronto Harbour for the Wastewater Treatment Technology Centre of the Ontario Ministry of the Environmental. Therefore, a total of 3,500 tons of material will be volumetrically reduced by the Bergmann USA plant.

Following the completion of the Canadian demonstration project, it is anticipated that a full-scale plant will be designed for installation of a three-year, 85-tons/hr (300,000-tons/yr) remedial project of the Toronto Harbour front area.

References for Appendices

1. Science Applications International Corporation (SAIC), San Diego, CA. April 17, 1992. "Demonstration Plan for Bergmann USA's Soil/Sediment Washing Technology."

2. U.S. Army Corps of Engineers (USACE). October 5, 1992. Facsimile transmission from Jim Galloway, USACE, Detroit District.

3. Bergmann USA. 1992. Bergmann USA Project Descriptions.

4. Science Applications International Corporation (SAIC). Buffalo, NY. October 1992. "Soil Recycling Treatment Train; The Toronto Harbour Commissioners; Evaluation of the Attrition Soil Wash Process."

Table D-1. Summary of Toronto Harbour Commissioners SITE Demonstration Test Results (mg/kg)

	Feed Soil[a,b]	Trommel Oversize[b]	Coal/Peat Fraction[c]	Clean Sand[b]	Contaminated Fines[b]
Oil & Grease	8,330	3,330	38,100	2,180	40,000
TRPH	2,540	814	11,900	621	14,000
Copper	16.9	2.40	32.9	13.8	80.9
Lead	115	23.0	406	46.0	520
Zinc	82.5	24.4	210	34.1	329
Naphthalene	11.2	2.62	64.0	2.05	51.7
Phenanthrene	6.91	2.36	39.0	1.77	34.7
Pyrene	5.06	1.79	33.0	1.43	26.3
Benzo(a)pyrene	1.91	0.580	14.5	0.530	10.0

[a] Feed soil characteristics were calculated from rock and fines analytical data using a weight basis.
[b] Average of six composite samples.
[c] Average of three composite samples.
TRPH Total Recoverable Petroleum Hydrocarbons.

☆U.S. GOVERNMENT PRINTING OFFICE: 1995-653-470